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ASSESSING THE IMPACT OF CLOTHING AND INDIVIDUAL EQUIPMENT (CIE) ON SOLDIER PHYSICAL, BIOMECHANICAL, AND COGNITIVE PERFORMANCE PART I: TEST METHODOLOGY

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Approved for public release; distribution is unlimited

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14. ABSTRACT
The objective of this study was to establish a test methodology utilizing an operational scenario for assessing the effects of clothing and individual equipment (CIE) on Soldier physical and cognitive performance. This objective was accomplished by translating established scientifically based cognitive and physical metrics into an integrated field test battery/scenario. The scenario was designed to have Soldiers perform an operationally relevant and fatiguing set of tasks (e.g., movement to an objective, action on an objective, etc.). Test participants performed six events in a 4-hour scenario each day over the course of 3 test days, with a rest day between each day of testing. The scenario sequence of events was as follows: 1. Pre-dynamic rifle marksmanship performance; 2. First 3-mile foot march at 3 mph; 3. Load Effects Assessment Program (LEAP) obstacle course; 4. Military Operations in Urban Terrain (MOUT) exercise; 5. Second 3-mile foot march at 3 mph; and 6. Post-dynamic rifle marksmanship performance. The knowledge products resulting from this research (Part I: Test Methodology and Part II: Data Analysis) will give insights to combat developers and commanders on the effects of existing CIE on Soldier performance. Part I focuses on providing a detailed description of the methodology, while Part II reports the results of the study.

15. SUBJECT TERMS

METRICS	MOVEMENTS	FOOT MARCHING	FATIGUE(PHYSIOLOGY)
TARGETS	BIOMECHANICS	ARMY PERSONNEL	RIFLE MARKSMANSHIP
TRAINING	DATA ANALYSIS	DATA COLLECTION	PERFORMANCE(HUMAN)
SCENARIOS	METHODOLOGY	OBSTACLE COURSES	PROTECTIVE EQUIPMENT
FIELD TESTS	LOAD CARRIAGE	TEST METHODOLOGY	OPERATIONAL SCENARIOS
STANDARDS	MARKSMANSHIP	POSITION(LOCATION)	COGNITIVE PERFORMANCE
CIE(CLOTHING AND INDIVIDUAL EQUIPMENT)			PPE(PERSONAL PROTECTIVE EQUIPMENT)

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PREFACE

This report documents a study carried out from June to October 2016 by researchers of the Biomechanics and Engineering Team, Cognitive Science Team, and Human Factors Team, with additional support from the Anthropology Team, Soldier and Squad Integration Team, and Office of the Chief Scientist, U.S. Natick Soldier Research, Development and Engineering Center (NSRDEC). Additional personnel support was provided by the U.S. Army Test and Evaluation Center and Fort Devens Range Control. The effort was funded by NSRDEC under the Research and Development Program 14-021, "Soldier Equipment Configuration Impact on Performance: Establishing a Test Methodology for the Assessment of Clothing and Individual Equipment."

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EXECUTIVE SUMMARY

The U.S. Army continually seeks to improve the clothing and individual equipment (CIE) used to outfit and protect the individual Soldier. This improvement is accomplished by assessing the acceptability of next-generation or novel protective equipment, as well as of field clothing, through limited user evaluations (LUE) of the candidate items. The results of these assessments have consisted mainly of subjective data in the form of participants' comments and opinions after performing simulated mission activities. While previous qualitative assessments have gleaned useful information, they have been limited in how they have investigated the quantitative effects of the test items on Soldier performance of relevant military activities. Further, laboratory studies provide a rich literature on cognitive and physical performance under conditions of load carriage that simulate some of the mission-relevant conditions Soldiers are asked to perform. However, there is additionally a need to assess equipment in a more operationally relevant context. Lastly, there is a need to create and validate a reliable and operationally relevant test bed for assessing the impact of CIE on Soldier physical, physiological, biomechanical, cognitive, and subjective task performance.

Therefore, the objective of this study conducted by researchers from Natick Soldier Research, Development and Engineering Center (JUN-OCT 2016) was to establish a test methodology utilizing an operational scenario for assessing the effects of CIE on Soldier physical and cognitive performance. This objective was accomplished by translating established scientifically based cognitive and physical metrics (which are sensitive to changes in CIE/fatigue) into an integrated, repeatable, field test battery that supports the methodology development. The scenario was designed to have Soldiers perform an operationally relevant and fatiguing set of tasks (e.g., movement to an objective, action on an objective, etc.).

In order to assess physical, physiological, biomechanical, cognitive, and subjective task performance, test participants participated in a 4-hour scenario each day over the course of 3 test days, with a rest day between each day of testing. The scenario sequence of events was as follows (see Figure 1 for scenario flow):

1. Pre-dynamic rifle marksmanship performance
2. First 3-mile foot march at 3 mph
3. Load Effects Assessment Program (LEAP) obstacles
4. Military Operations in Urban Terrain (MOUT) exercise
5. Second 3-mile foot march at 3 mph
6. Post-dynamic rifle marksmanship performance

Repeating the marksmanship and foot march performance tests allowed for assessment of the CIE in rested and fatigued states.

Throughout each of these events, physical, physiological, biomechanical, cognitive, and subjective task performance were recorded. The implementation of the methodology called for participants to complete the operational scenario three times while wearing three different equipment configurations to provide within-subjects measures of performance. However, this test methodology could be implemented with any number of equipment conditions and a variety of

Soldier-relevant performance tasks. Additionally, this methodology was designed to be employed in a variety of locations and environments, depending on the goals of the evaluation.

The knowledge products resulting from this research will give insights to combat developers and commanders on the effects of existing CIE on Soldier performance. It will also provide a science-based tool for evaluating the trade-space between changes in CIE and Soldier performance. In addition, the lessons learned from this effort can be used to refine future iterations of this test methodology. A follow-on Part II of this report will address the specific results and analysis from the implementation of the methodology described in this report.

ASSESSING THE IMPACT OF CLOTHING AND INDIVIDUAL EQUIPMENT (CIE) ON SOLDIER PHYSICAL, BIOMECHANICAL, AND COGNITIVE PERFORMANCE
PART I: TEST METHODOLOGY

1. INTRODUCTION

1.1 Background

The U.S. Army continually seeks to improve the clothing and individual equipment (CIE) used to outfit and protect the Soldier. This improvement is accomplished by assessing the acceptability of next-generation or novel protective equipment, as well as of field clothing, through limited user evaluations (LUE) of the candidate items. The results of these assessments have consisted mainly of subjective data in the form of participants' comments and opinions after performing simulated mission activities. While previous qualitative assessments have gleaned useful information, they have been limited in how they have investigated the quantitative effects of the test items on Soldier performance of relevant military activities. Further, laboratory studies have provided a rich literature on cognitive and physical performance under conditions of load carriage that simulate some of the mission-relevant conditions Soldiers are asked to perform. However, there is additionally a need to assess equipment in a more operationally relevant context. Lastly, there is a need to create and validate a reliable and operationally relevant test bed for assessing the impact of CIE on physical, physiological, biomechanical, cognitive, and subjective task performance.

The operational scenario based study was conducted by researchers from Natick Soldier Research, Development and Engineering Center (NSRDEC) during the months of June to October, 2016. This report is based on a mixture of controlled laboratory and field environment assessments that have been run independently in previous research, and are specifically structured to inform acquisition decision makers on the performance of CIE. When developing the test methodology for the evaluation of CIE, task relevancy, reliability of metrics, and consistency of test measures are important considerations. Scientists from the NSRDEC Biomechanics and Engineering, Cognitive Science, and Human Factors Teams in previous research have established common measures of performance in the form of Soldier relevant field test metrics. These include controlled road marches, Load Effects Assessment Program (LEAP) obstacles, a Military Operations in Urban Terrain (MOUT) course, and marksmanship tasks. The foot march distance, pace, and CIE conditions used in this evaluation have been established in previous laboratory testing that have produced relevant and reliable biomechanics, physiologic, and dynamic cognitive data (Eddy et al., 2015). NSRDEC has established the independent use of the LEAP obstacle course as a means to discern personal protective equipment (PPE)/CIE performance differences in a controlled setting. Timed runs of obstacle courses, which require such activities as jumping, crawling, climbing, and balancing, have been used extensively in studies to evaluate different designs of load-carriage equipment (Brainerd & Bruno, 1985; LaFiandra et al., 2003; Pandolf et al., 2003).

The MOUT course has been used independently and in combination with obstacle courses to evaluate specific Soldier relevant tasks and Soldier CIE effects on physical and cognitive performance (Hasselquist et al., 2013; LaFiandra et al., 2003). The weapon simulator system has been used and techniques have been verified in several NSRDEC studies (Baca et al., 2012; Hawkins & Sefton, 2011; Tharion et al., 2003; Warber et al., 2002). Scientists from the NSRDEC Cognitive Science Team have established dynamic cognitive tasks that address the previous issue of limiting relevant data due to the rapid recovery of cognitive process and function following physical exertion by being able to assess cognitive performance *during* event execution (e.g., during the foot march instead of pre/post). The establishment of new methods and measures to explore the effects of CIE/PPE equipment on cognitive processes and performance have been explored as a task concurrent to physical task performance in controlled independent laboratory and field tests (Eddy et al., 2015). It is important to have a methodology with high energy and stress level activities with controlled down times that add validity to the overall event and data. The Soldier component tasks selected and the specific order of presentation (i.e., first foot march and initial marksmanship before physical taxing efforts of the LEAP and MOUT and then second foot march and secondary marksmanship after exertion) may reveal meaningful differences between equipment components due to differences in equipment weight and bulk of the CIE conditions being tested.

1.2 Objective

Program 14-021, "*Soldier Equipment Configuration Impact on Performance: Establishing a Test Methodology for the Assessment of Clothing and Individual Equipment*," was initiated to develop an operationally relevant scenario for the assessment of CIE. The purpose of this study was to establish a test methodology utilizing an operational scenario for assessing the effects of CIE on Soldier physical, biomechanical, and cognitive performance. The scenario was designed to have Soldiers perform an operationally relevant and fatiguing set of tasks (e.g., movement to an objective, action on an objective, etc.). Previous work characterizing the effect of CIE on Soldier performance has typically focused on one domain (e.g., physical, biomechanical, or cognitive), and featured a limited set of Soldier tasks (e.g., only foot marching), did not provide continuously fatiguing tasks, and did not necessarily implement rigorous scientific control. Therefore, this effort was aimed at addressing these gaps by developing a multi-disciplinary, controlled, and operationally relevant test methodology by translating established, scientifically based cognitive, biomechanical, and physical metrics (those which are sensitive to changes in CIE/fatigue) into a field test scenario. The intention of this report is to establish a methodology for assessing the impact of CIE on cognitive, biomechanical, and physical human performance, based on an operational field study that was recently completed. A follow-on report will document the results, analyses, and discussion of the field study that utilized this test methodology.

1.3. Approach

Data were collected from 62 participants while they performed an approximately 4-hour operational scenario. This report outlines the methodology for the operational scenario used for assessing equipment and how to execute this scenario. Throughout the scenario, data were collected to characterize physical, biomechanical, and cognitive performance. This methodology was designed to address CIE evaluations on an individual Soldier basis. The validation of the

scenario and measurement techniques used in the methodology must be confirmed before they can be expanded to squad-level assessments. The ability to evaluate Squad performance with new forms of CIE will be an important advancement of this methodology. Further research is warranted when using this methodology as a tool to address the effects of CIE on Soldier performance interaction within a squad and eventually the performance of the squad itself.

The order in which the participants were exposed to the test conditions was balanced to avoid bias and confounding in the data. While any CIE configurations can be used, in the case of this study, the conditions assessed were as follows:

- Condition I: No body armor, ancillary equipment consisting of an advanced combat helmet (ACH), boots, Army combat uniform (ACU), and mock M4 carbine (16.2 lb, 20.6 lb with small tablet pack for foot march).
- Condition II: Plate carrier (Soldier Plate Carrier System (SPCS)) body armor with front, back, and side plates plus ancillary equipment consisting of ACH, boots, ACU, mock M4 carbine, and a representative fighting load (68.0 lb, 101.9 lb with Modular Lightweight Load-carrying Equipment (MOLLE) pack).
- Condition III: Body armor vest Improved Outer Tactical Vest (IOTV) with front, back, and side plates; groin, kidney, shoulder, and neck/throat protection; and ancillary equipment consisting of ACH, boots, ACU, mock M4 carbine, and a representative fighting load (78.7 lb, 112.7 lb with loaded MOLLE pack of soldier items).

Note. Actual weights of the testing conditions may reflect small variations due to differences in weight of the clothing and equipment as a function of size and variations in manufacturing.

1.4. Schedule of Events

The method described here was intended to be used as a within-subjects design (i.e., each participant serves as their own control). In the study, each participant wore each of the three CIE conditions listed above on different test days separated by at least 1 rest day. Order of presentation was quasi-randomized. However, this method could be implemented to compare two or more equipment configurations. If future researchers are interested in determining performance relative to legacy equipment configurations, then it is recommended that the baseline condition be the legacy condition. If the researchers are interested in the impact of equipment on performance relative to no equipment, then it is recommended that the baseline condition be an unloaded/no equipment configuration. In some cases (e.g., the obstacle course or dynamic marksmanship task), an unloaded and/or rested configuration may also be of benefit. An example test schedule is shown in Table 1.

Table 1. Schedule for Four Groups.

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Travel	Orientation/ Briefings Demographics Anthropometry Equipment Sizing	Trainings Individual Components (Marksmanship, MOUT, Foot March, LEAP) Operational Scenario	Trainings Individual LEAP Components	1st Condition Operational Scenario Group 1 AM Group 2 PM	1st Condition Operational Scenario Group 3 AM Group 4 PM	Make-up Day REST
Day 8	**Day 9**	**Day 10**	**Day 11**	**Day 12**	**Day 13**	**Day 14**
REST	2nd Condition Operational Scenario Group 1 AM Group 2 PM	2nd Condition Operational Scenario Group 3 AM Group 4 PM	3rd Condition Operational Scenario Group 1 AM Group 2 PM	3rd Condition Operational Scenario Group 3 AM Group 4 PM	$VO2_{peak}$ Test AAR/Focus Groups Groups 1-2	Make-up Day REST
Day 15	**Day 16**	**Day 17**	**Day 18**	**Day 19**	**Day 20**	**Day 21**
REST	$VO2_{peak}$ Test AAR/Focus Groups Groups 3-4	Make-up Day	Make-up Day	Make-up Day	Make-up Day	Travel

1.5. Overall Operational Scenario Description

The participants began the scenario, consisting of a series of test events. These events took place over 3 nonconsecutive days divided by a rest day between each test day for each condition. The implementation of this scenario involved testing 8-12 participants per day based on the time available to test each day. In addition to providing the timing scheme shown in Table 1, separate appendices for each test station procedure/protocol are included at the end of this report.

To execute the scenario as designed, the following procedure was developed.

1. When participants arrived for testing, they first donned the inertial measurement units (IMUs), heart rate (HR) monitor, and condition configuration for the scenario. Prior to starting the scenario, participants also completed a checklist to ascertain daily changes in health status.

2. Participants began one at a time and were staggered by 20 min to avoid overlap on the foot march (see Appendix A for a timing schema for executing this methodology). An additional 10-min delay was added after every five participants to ensure proper spacing on the foot march. This allowed for any adjustments due to possible overlap of participants on the second foot march if there was a delay in finishing the LEAP and MOUT tasks.

3. *Pre-Dynamic Marksmanship:* After the participant was dressed in the test configuration and equipped with an HR monitor and IMUs, they went to the dynamic marksmanship station. This was the pre-dynamic marksmanship event and was the first event participants completed each day. This station took approximately 15 min to complete. Prior to starting, participants gave their Rating of Perceived Exertion (RPE) and they started the HR GPS

watch. After completion of the test, they gave their RPE again along with a Mission Performance Rating and the HR GPS watch was stopped.

4. *First Foot March:* After completing the Pre-Dynamic Marksmanship, the participant went to the foot march start station. The march was a 3-mile event at a controlled pace of 3 mph. Because of the 20-min staggering implemented to ensure Soldiers were walking independently, there was a brief pause at the foot march station to ensure the participant started at the correct time. For implementation of this methodology, a large timing clock should be used to ensure participants could see the correct time. During the pause, participants were equipped with either a rucksack or small backpack, in-ear headphones that were attached to the tablet carried in their pack, the hand-held USB response device, and a weighted mock M4. In test conditions with a load, a MOLLE pack was worn during the march and a small backpack was worn when the condition was no-load/no-equipment. Prior to starting the foot march, participants provided an RPE. When participants began the foot march, they pressed the USB response device to start the task and the start button on the HR GPS watch. Throughout the march, there were signs that gave the participant feedback as to whether or not they were on pace (e.g., at 0.25 miles, the watch should have read 5 min). In addition, at three points on the course, test staff were stationed to provide water, troubleshoot issues participants may have been having, and perform a safety check. These stations noted the time at which the test participant arrived and if their pace was too slow or too fast. Upon completion of the first foot march, participants doffed the MOLLE pack, mock weapon, headphones, and response device, provided an RPE and Mission Performance Rating, and stopped the HR GPS watch. They then proceeded to the LEAP obstacle course.

5. *LEAP Obstacle Course:* Participants went straight from the foot march station to the LEAP station. When they arrived, they gave a RPE. Prior to starting the obstacle course, they started the HR GPS watch. They completed the obstacles in the prescribed manner with a maximal effort. After completing the LEAP course, participants stopped the HR GPS watch, gave an RPE and Mission Performance Rating, and immediately proceeded to the MOUT.

6. *MOUT:* When participants arrived at the MOUT, they were given the demilitarized weapon with a mounted FN Expert optic and donned a Go-Pro camera on their helmet. In addition, they donned a Shotmaxx watch on their dominant shooting wrist with their sleeve rolled up to avoid any recordings of false shots. Prior to starting the MOUT task, participants gave an RPE and started the HR GPS watch. To initiate timing for the task, a Shotmaxx competition watch counted down 2 s and then beeped to indicate that the participant should engage the first target outside the MOUT facility door, marking the start of the sequence. The participant then completed room clearing and the shoot/don't shoot task. After completing the MOUT, participants gave their RPE and Mission Performance Rating, stopped the heart watch, and gave the tester the Go-Pro, Shotmaxx watch, and the weapon with mounted FN Expert optic (see Section *3.5 MOUT* for details on executing). Because of the 20-min staggering implemented to ensure Soldiers were walking independently, there was a brief pause at the foot march station to ensure the participant started at the correct time.

7. *Second Foot March:* The participant returned to the start of the foot march where they donned headphones, the hand-held response device, mock weapon, and either a MOLLE pack or small backpack with the tablet (depending on the equipment condition) and executed the 3-mile road march at 3 mph for a second time. They provided RPE ratings at the start and finish of the march, as well as Mission Performance Ratings at the end, and then proceeded to the weapon simulator for post-marksmanship testing.

8. *Post-Dynamic Marksmanship*: To finish the scenario, participants went through the dynamic marksmanship station a second time in the exact same way as they did the first time through.

9. *End of Day Questionnaires*: When the marksmanship testing was completed, marking the completion of the scenario, participants completed the pain and discomfort scale and human factors questionnaires (see Appendix A).

The diagram of the tasks associated with the operational scenario is shown in Figure 1.

Figure 1. Diagram of the Tasks Associated with the Operational Scenario.

2. SUPPORTING TEST EVENTS

2.1. Demographics

Demographics questionnaires were completed during the orientation session (Appendix A). These questionnaires were used to obtain age, rank, foot and hand dominance, physical fitness and marksmanship testing scores, health/exercise history, experience wearing body armor and other CIE, and injury history. This information was used as covariates in statistical analyses.

2.2. Sizing and Anthropometry

Sizing for proper fit of CIE was accomplished during the orientation session. CIE were available in a variety of sizes. When body dimension measurements were taken, test participants were asked to remove their boots and all clothing (other than their trousers) and to empty their pockets. The measurements for each participant taken were as follows: weight, stature, crotch height, head length, head breadth, head circumference, neck circumference, chest circumference, and waist circumference at the omphalion. Measurements were made in accordance with the procedures in the 2014 anthropometric survey of the U.S. Army personnel measurer's handbook (Hotzman et al., 2011; Gordon et al., 2014). One tester, experienced in the measuring of body dimensions, took the measurements on all test participants. A fit/sizing session was conducted by personnel experienced in the fit of the body armor systems to ensure that all participants were outfitted in acceptably fitting CIE items that comprised the three test conditions. The participants were then sized to the proper CIE. The participant used their determined best fit sized CIE for the duration of the study.

2.3. Training on Tasks

Two days at the beginning of the study were dedicated to familiarization with the tasks. Additional information on the training for each specific task is included in the task description below.

After training on all individual components of the scenario, the complete sequence of events was practiced to familiarize participants with the transitions between events of the operational scenario. This practice exposed the participants to the linked components of the course and familiarized them with the sequence of events for the operational scenario days. Participants performed this walk-through individually in the Condition I configuration.

2.4. Determination of $\dot{V}O_{2Peak}$

The determination of $\dot{V}O_{2Peak}$ for each participant was assessed to establish true maximum HR to determine physiological measures of heart rate reserve (HRR). This measure was assessed after scenario testing was completed on a day that featured no other physical activities. This information was used to describe the participants and as covariates in statistical analyses. Peak oxygen uptake was measured using a continuous, uphill, and stepwise treadmill protocol. No load was worn during the $\dot{V}O_{2Peak}$ assessment. A study team member experienced in such testing monitored the participant's HR throughout the testing. The participant first warmed up by running on the treadmill for 5 min at 2.22 m/s on a level grade. After a 5-min rest, the participant began running on the treadmill at a 5% grade and a speed determined to be manageable based on the participant's

feedback and HR during the warm-up run. The participants wore a lightweight mask that covered the oronasal portion of the face. The mask was connected by a flexible hose to a Quark CPET metabolic cart (COSMED, Rome, Italy) that monitored oxygen uptake. Every 2 min, the treadmill grade was increased by 2.5% without changing the speed. The test continued until the participant had achieved $\dot{V}O_{2Peak}$ based on American College of Sports Medicine (ACSM) criteria. Normally, participants reach peak oxygen uptake within 10 to 15 minutes after starting the test (ACSM, 2010). The HR, the RPE Scale (Borg, 1970; see Appendix A), and cardiorespiratory measures from the metabolic system (oxygen uptake, ventilation, etc.) were continuously monitored during the test in order to assess physiological responses.

2.5. Focus Group/After Action Review

At the conclusion of the operational scenario testing, participants participated in a discussion of a set of focus group questions about the overall assessment and the equipment configurations they wore. Focus groups consisted of 6-10 individuals.

2.6. Discussion of Lessons Learned From Supporting Test Events

There were several lessons learned during the supporting test events. The following were the primary issues that should be considered for future execution of this task:

- Improved explanation of the rating scales should be provided during the orientation and training, including to the study team. While descriptions and explanations of the test scales were given to the participants, some participants still lacked full understanding.
- Execution of the $\dot{V}O_{2Peak}$ testing can occur on any day participants are fully rested and not completing additional physical testing (i.e., during orientation, rain days, or at the conclusion of testing). This allows for flexibility in the schedule testing utilization of rain days.
- Due to human use protocols, a medic was stationed on site to mitigate health risks during all test events.
- While, for the purposes of this study, focus group questions focused primarily on the methodology of the operational scenario, CIE assessments would instead focus on the characteristics and design features of the test items and the impact those (subjectively) had on performance (both physical and cognitive).
- Encumbered anthropometry and encumbered range of motion should be considered as additional supporting test events (in each test configuration) to better understand the impact on bulk and/or joint movement. The Jackson Strength Test (Lafayette Instrument, Lafayette, Indiana, USA) has shown strong correlations with LEAP obstacle course performance (Mitchell et al., 2017). Participants should complete the strength test in an unloaded configuration as part of the supporting test events.

3. MISSION TEST EVENTS

3.1 Start of Day Tasks

3.1.1 Daily Briefing

Soldiers were assigned to their configuration and to their day of testing. Prior to the start of each day's session, participants were asked to complete a checklist of questions to ascertain daily changes in health status, recent injuries, amount of sleep, and diet. The checklist was not used exclusively to terminate participation; if the participant reported any changes or injury, soreness, pain, or discomfort, a consultation with Office of Medical Support and Oversight (OMSO), unit medic, and the Principal Investigator (PI) would determine the status of continued participation. (Pre-Test Status Data Sheet, see Appendix A). Additionally, the range officer and/or safety personnel provided a daily comprehensive briefing on any updated safety, weather, and health status of participants for the field study location.

3.1.2 Soldier Preparations

Prior to the scheduled test events of each day, the Soldiers were assigned their configuration condition. The Soldiers were then refreshed on the scenario test course procedures highlighting any relevant information from the preceding days of testing. The participants then reported to the data collectors for IMU and HR monitor set up.

3.1.3 IMU Preparation

The biomechanical data in this methodology utilized IMUs for data collection in a field environment. NSRDEC is currently working to systematically advance IMU technologies as they pertain to human motion, to achieve a prototype for reliably assessing warfighter performance in naturalistic settings. During all events of this operational scenario, the trunk kinematics and lower limb spatial temporal measures were quantified from the data of four precisely attached IMUs sampling at 128 Hz. The IMUs were attached to the trunk, sacrum, and both feet (bilateral foot placement).

3.1.3.1. IMU Placement

The IMUs, containing a three-axis gyroscope (±2000°/s) and a three-axis accelerometer (±6 g), were attached and secured to the participant's skin surface of the trunk, sacrum, and both feet with an elastic strap and cohesive athletic tape. Specifically, IMUs were attached to the sternum, the pelvis as close to the sacrum as possible, and the boot laces at the instep of each foot. Optimal placement and challenges of IMU movement have been addressed in previous work (Cain et al., 2014; McLean et al., 2015). Wraps and taping techniques were also addressed in this previous research, and the same techniques were used in the current protocol. The wrapping techniques minimized IMU movement while remaining flexible enough to allow comfortable contraction of the muscles. These techniques helped secure lower limb IMUs, but did not translate to the sacrum and sternum sensors. These two sensors were placed in such a way that any additional wrapping or taping would result in restricted and uncomfortable movement. The addition of flexible tape

over the built-in straps that came with the sensors would be considered an adequate technique for securing these IMUs during data collection. However, limiting the number of straps placed on the Soldier is an important issue when participant comfort and time constraints of sensor application are considered. In this study, researchers were able to address the security of the sacrum and torso sensors without the addition of the extra strapping, thereby reducing the number of additional straps placed on the Soldier. This was accomplished by incorporating the posterior belt loop of the Soldier's ACUs for the sacral marker attachment, using the HR monitor strap for the torso sensor attachment, and then securing both sensors with flexible tape. In addition to the body-mounted IMUs, a separate IMU was used solely to mark the transitions between the separate tasks of the operational scenario. This IMU had a trigger button that was pressed by data collectors to indicate the beginning and end of the IMU calibration motions, the foot marches, and each LEAP obstacle. Study participants carried this IMU in their shoulder pocket for the duration of each scenario task.

3.1.3.2. IMU Calibration

Following IMU attachment, each participant performed a series of calibration motions consisting of three specific movements: 1) standing upright and still (~10 s); 2) four toe touches; and 3) straight walking (~10 m). The calibration motions were used after data collection, during post-processing, to align the IMU axes with the underlying body segment (anatomical reference frame), thereby removing error related to the positioning of the IMUs during data analysis. Specifically, the standing data were used to define the superior-inferior axis for each IMU, the toe touch data were used to define the medial-lateral axes for the sternum and sacrum IMUs, and walking data were used to define the medial-lateral axes for the feet. Lastly, the anterior-posterior axes were determined by taking the cross product between the two already calculated axes for each IMU. If an IMU shifted during the proposed testing, the calibration would have been repeated at the end of the testing session. However, there were no IMU shifts reported during this study.

3.1.4 Heart Rate Monitor Preparation

The HR of each participant was monitored during all testing sessions using the Garmin Forerunner 220. The Forerunner 220 measures essential data including distance, pace, and HR. In addition to using GPS to calculate distance and pace, the 220 has a built-in accelerometer. The accelerometer can also track distance when GPS is unavailable. This system consists of a wrist monitor and a chest strap. For this test event, each participant donned the chest strap prior to initiating each test session and wore it throughout testing. Data were collected continuously throughout each test session. The chest strap contained a transmitter that sensed HR and sent information about HR to the Garmin unit. The HR monitor was then interfaced with the Garmin software and information was stored for later analysis. Initial resting HR was recorded after sitting and after standing quietly for ~5 min. The HR monitor watch was started at the beginning of the dynamic marksmanship tasks, both foot march tasks, LEAP and MOUT and at the completion of each of these tasks. The participant's HR data were then downloaded at the end of the day from the Garmin 220 HR Monitor into data files within the Garmin computer software. For each equipment condition, maximum and mean HRs were then calculated during specific tasks of the scenario (foot marches, LEAP, and MOUT tasks). The HRR was then calculated as a measure of percent exertion (%Exertion) for each task using a modified equation from the Karvonen Method:

$$Target\ HR = (fractional\ intensity)(HR_{max} - HR_{rest}) + HR_{rest} \quad (1)$$

This method required the use of the HR_{max} recorded for each individual during their $\dot{V}O_{2Peak}$ test, the HR_{rest} recorded at the start of the day's trial, and the mean or maximum HR achieved during the task under analysis (i.e., foot march, LEAP, or MOUT). HRR relative to the maximum HR exhibited during each task ($HRR_{maxtask}$) was calculated by rearranging terms after the substitution of %Exertion for fractional intensity and $HR_{maxtask}$ for Target HR:

$$HRR_{maxtask} = \%Exertion = \frac{HR_{maxtask} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100 \quad (2)$$

Similarly, HRR relative to the mean HR exhibited during each task ($HRR_{meantask}$) was calculated by substituting $HR_{meantask}$ for $HR_{maxtask}$:

$$HRR_{meantask} = \%\ Exertion = \frac{HR_{meantask} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100 \quad (3)$$

*Example: Assume a soldier achieved an $HR_{maxtask}$ of 195 bpm and an $HR_{meantask}$ of 165 bpm for the LEAP section. Their resting HR was 62 for that day. Their HR_{max} from the VO2peak test was 206 bpm. The Soldier's $HRR_{maxtask}$ on the LEAP course would be 92% and their $HRR_{meantask}$ would be 72%.

3.1.5 Discussion of Lessons Learned From Daily Preparations

There were several lessons learned during daily preparations. The following were the primary issues that should be considered for future execution of this task:

- When zip-tying and taping the boot IMU on the laces, avoid adhering tape to the soles because the tape edges will gather significant soil, grass, and gravel over time.
- Cover the strap with pre-wrap and tape to ensure the strap does not fall down the torso during the operational scenario. This is especially important if using a strap to secure the sternum IMU that does not wrap over the shoulders. The pre-wrap will prevent direct tape-to-skin contact.
- Ensure the number and locations of IMU trigger button presses during the IMU calibration motions and operational scenario are identical across trials for simpler post-processing.
- For the heart rate monitor watch, ensure every participant's watch is set to the pace or speed screen before beginning the operational scenario to avoid participant or data collector confusion at each task.
- Document steps for starting, stopping, and troubleshooting issues with the watch for each station.
- Due to the staggered start approach of each individual participant, those who started at the beginning or end of the day had long stretches of inactivity. This especially caused pressure on the last few participants of the day, who may have felt rushed. By adding another activity that can be completed during the down time or allowing individuals to arrive in shifts, it may reduce this extended period of inactivity.

- If females act as participants, it is recommended that waist circumference at natural indentation and buttock circumference be added to the anthropometric measures (for females only), to allow for the computation of body fat.

3.2 Dynamic Marksmanship

3.2.1 Marksmanship Background

Previous research has shown that marksmanship performance and latency to acquire and engage targets are detrimentally affected by CIE (McNamara et al., 2016; Frykman et al., 2012). Numerous research efforts have utilized weapon simulator systems to determine the effects of postural stability on marksmanship performance (Baca & Kornfeind, 2012; Hawkins & Sefton, 2011), as well as the effects of supplements on marksmanship in a stress-induced training environment (Tharion, Shukitt-Hale, & Lieberman, 2003; Warber, Tharion, & Patton, 2002). Development of a test methodology using the FN Expert Weapon Simulator (FN America, McLean, VA) for CIE testing has been underway for several years. McNamara et al. (2016) developed a five-target methodology that focused on the timing required for target engagement across the vertical and horizontal plane from a static location, providing additional information on aiming, transition, and engagement times. In this current study, the dynamic marksmanship task builds upon the five-target method, providing a more active scenario that captures the entire target acquisition and engagement sequence (Brown, McNamara, & Mitchell, in press). This scenario requires participants to reposition the entire body, reposition the weapon, and realign the sights prior to target engagement, thereby highlighting the CIE interferences with the gross body movements.

Marksmanship data were collected using the FN Expert Weapon Simulator mounted on a demilitarized M4 carbine with an integrated CO2 recoil simulation system (LaserShot, Stafford, TX). The FN Expert Weapon Simulator consists of an optical unit and software package loaded on a laptop computer. The optical unit can be mounted on the barrel or Picatinny rail system of any rifle or carbine, and emits an eye-safe infrared (IR) light emitting diode (LED) beam. The optical unit also contains an accelerometer that detects the vibration when an operator pulls the trigger. The FN Expert Weapon Simulator is able to record and display muzzle trace, location of miss or hit for a shot, and allows for analysis of various performance measures, and has been validated as equivalent to live fire for gross marksmanship measures, such as probability of hit and probability of lethal hit (Brown et al., 2016). The marksmanship tasks used two types of system-specific scaled targets, which contained reflectors that allowed the optical unit to capture the reflected IR beam of the unit when aimed at the target (Figure 2).

Paper ring targets, incorporating FN Expert specific diamond grade (DG) reflector rings, were used in the stand-alone marksmanship activities at the beginning and at the end of the scenario. The targets used in the dynamic task were scaled to represent 75 m when placed at a distance of 5 m. Scaled E-type silhouette targets, incorporating FN Expert specific P38 prism reflectors and Hit Indication Beam (HIB) modules, were used during the MOUT scenario.

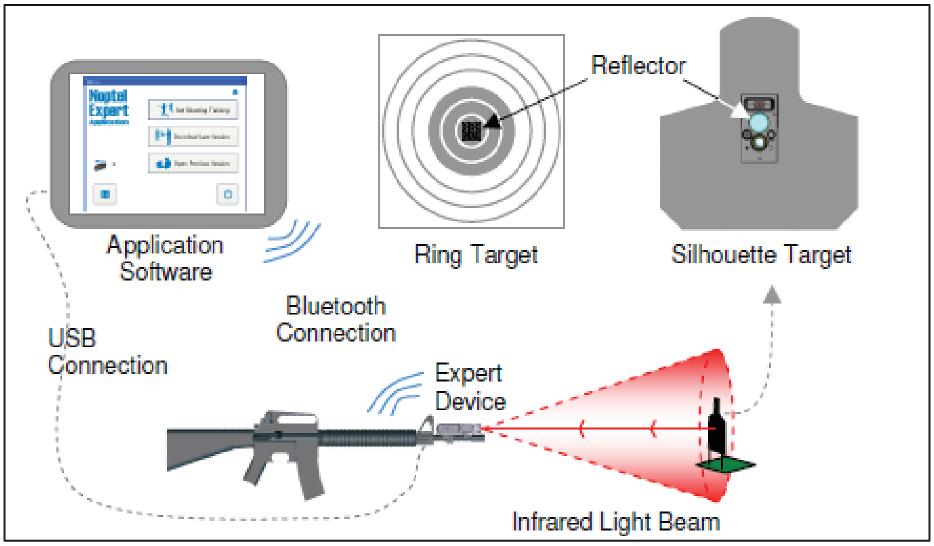


Figure 2. Diagram of the FN Expert Training System.
Source: Noptel Expert Application User's Guide 2.1, Noptel Oy, OULU.

3.2.2 Dynamic Marksmanship Task Setup

Generally speaking, the equipment needed for this task is as follows: FN sensor, weapon, computer or tablet, target stands, 30 ft x 20 ft open space, and paper targets. Weather conditions should be dry, with a light mist considered acceptable. The dynamic course should be set up according to the diagrams in Figure 3, using the DG Ring targets, and ensuring that the targets are level to the ground. The firing lanes should be cleared of any hazards or interferences.

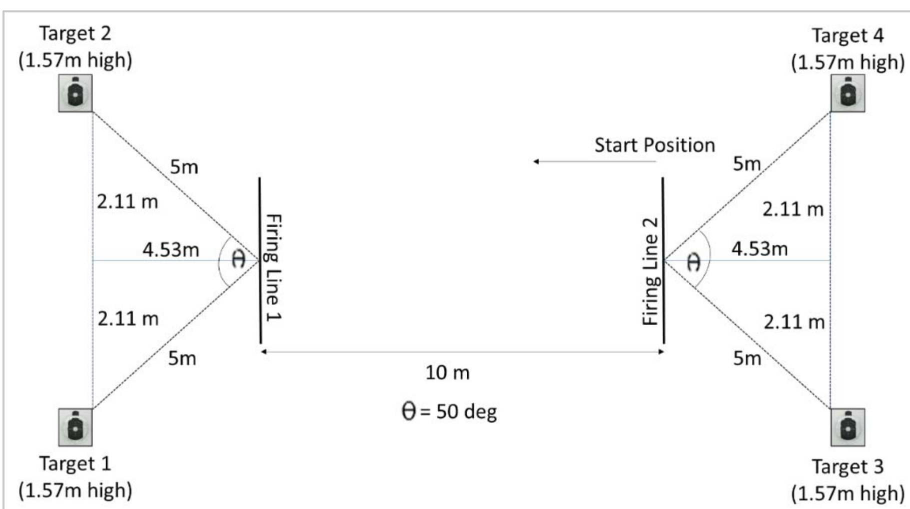


Figure 3. Dynamic Marksmanship Course: Four Target Setup.

The FN Expert software records shot performance data in real-time and presents multiple statistical calculations, individual shot scores, and time between shots. On each scenario day, the NOS Pro Fabrique National (FN) software application must be opened, ensuring that the correct position of the optical unit is selected (this study mounted the optic on the right side of the barrel using the

Picatinny rail), and that the correct optical device is connected via Bluetooth. Then, the FN Expert optical unit must be mounted on the weapon and aligned with the weapon's sighting system (a parallax-free system, such as the Close Combat Optical unit M-68, is recommended as it will reduce the time required for software zeroing and is more representative of operational conditions). Once the FN expert optical unit is mounted on the weapon, the weapon must be placed in a gun vise and aligned such that the sights are aimed at the center of a target. The optical unit must be mechanically adjusted following the FN Expert User's Guide instructions, such that the optical unit is aiming at the center of the reflector ring when the sights are aimed at the center of the target from a vice on a steady table top. Finally, the correct target must be selected in the application based on the simulated distance (75 m), target type (ring), and weapon type (M4 or AR/RK) prior to each participant's event start time.

3.2.3 Dynamic Marksmanship Training

Each participant completed the following Practice/Qualification procedure:

- Each participant fired 10 shots at the paper ring DG target placed 5 m (simulating 75 m) in front of the shooter in the standing, kneeling, and prone unsupported firing positions (10 shots in each firing position, for a total of 30 shots). The marksmanship qualifications of each participant were evaluated as follows:
    - ✓ If 7 of the 10 shots were within the "6" ring (black area) of the target, the shooter was considered qualified for the Standing Unsupported firing position
    - ✓ If 8 of the 10 shots were within the "6" ring (black area) of the target, the shooter was considered qualified for the Kneeling Unsupported firing position
    - ✓ If 9 of the 10 shots were within the "6" ring (black area) of the target, the shooter was considered qualified for the Prone Unsupported firing position
- Provided the shooter met the minimum qualification standards for each of the firing positions as outlined above, they were considered qualified to participate in the evaluation. If the shooter did not meet these minimum qualification standards, they were given additional practice until they were able to meet these standards. If they were unable to meet these standards after 10 attempts, data from their marksmanship trials were not used for analysis.

After completing the practice/qualification procedure, each participant was given an opportunity to practice the marksmanship activities. A study team member explained the shooting events. The participants needed to execute the activities in the manner instructed each time the testing scenario was attempted. Participants completed two practice trials: one in the baseline condition and one in an equipped condition (i.e., Condition I and Condition II, at a sub-maximal effort, that is 50-75% max effort).

3.2.4 Description of Dynamic Marksmanship Task

At the start of the dynamic marksmanship event, the participants were asked for their RPE rating and their heart rate monitor was initiated. The participants were then given their randomized engagement order for the scenario day (Standing Unsupported, Kneeling, and Prone firing positions). The entire Table of Fires (multiple target locations and multiple firing positions) took approximately 30 min per configuration/test condition. Prior to starting the event, the participant first software zeroed their weapon in the Prone position, shooting three shots at the scenario target,

which were then centered on the target by the NOS Pro application. Note that the target height used in the software zero was the same as the scenario target height of 1.57 m.

When ready and when the NOS Pro application was recording, the participants first executed the one target scenario, presented in Section I of Table 2, firing five series of five shots in each firing position (Standing Unsupported, Kneeling, and Prone). The participant was instructed to be deliberate with their shots, keeping accuracy as their priority over speed. The order of presentation of firing positions is pseudo-randomized across participants.

Table 2. Summary of Table of Fires.

Table of Fire		Scenario	Firing Position	No. of Trials	No. Shots per Trial	Total No. Shots
I	A.	One Target	Standing Unsupported	5	5	25
	B.	One Target	Kneeling	5	5	25
	C.	One Target	Prone	5	5	25
II	A.	Dynamic	Standing Unsupported	1	8	8
	B.	Dynamic	Kneeling	1	8	8
	C.	Dynamic	Prone	1	8	8

The participant then continued into the dynamic scenario, presented previously in both Section II of Table 2 and in Figure 3. The dynamic marksmanship scenario consisted of two firing lines spaced 10 m apart. While executing each trial, the participant began by standing at one of the firing lines, turning 180°, and sprinting 10 m to the second firing line. They then assumed one of the firing positions (standing, kneeling or prone). The participant then engaged the two targets, firing a controlled pair (two shots) first at the left target and then at the right. After the participant engaged the second target, they turned around (180°), sprinted 10 m back to the other firing line, and engaged the two targets, firing a controlled pair first at the right target and then at the left, in the same body posture they uses at the previous firing line. This process completed a single trial with a total of two sprints and eight shots per trial. The participants completed one trial in each firing position for each configuration. While executing the dynamic task, the participant was instructed to assume the firing position, acquire the targets, and engage the targets as quickly as possible without sacrificing accuracy.

Upon completion of the last dynamic test in the final firing position, the test participants were asked to provide their RPE score and mission performance score, and their heart rate monitor was stopped. After completion of the pre-dynamic scenario, the participant proceeded to the road march

task. After completion of the post-dynamic scenario, the participant completed the human factors questionnaire and doffed their equipment, and the session was complete.

3.2.5 Discussion of Lessons Learned From Dynamic Marksmanship Task

There were several lessons learned from the dynamic marksmanship task. The following were the primary issues that should be considered for future execution of this task:

- In order to keep mechanical zero relatively consistent throughout the testing, have a designated researcher initially set the zero and then keep the optical sensors on the weapons until testing is complete. This will reduce the amount of daily set up time, as checking the zero should be relatively quick as compared to initializing the zero daily. It will also reduce issues with variability across researchers during the zeroing process.
- Software zeroing the weapon should be conducted in the prone position, as it is the most stable of the firing positions. However, shooting in the prone position at 5 m when using a target scaled to 75 m, at a height of 1.57 m will result in a very steep angle for the shooter, resulting in a non-typical sighting position and eye-alignment with the weapon. Although the M-68 optical unit is designed to be parallax-free for distances greater than 50 m, the real distance in this study was closer, thereby causing some occurrences of misalignment. These misalignments are especially apparent when using the unit for shooting at great angles. To ensure that the software zero is correcting for the shot alignment in the manner as designed, the zeroing should be conducted in the prone position at a target that is located .10 m from the ground (i.e., essentially level to the shooter). Alternatively, zeroing can be conducted in a supported kneeling or standing position while utilizing the targets at the height of 1.57 m.
- Trigger sensitivity can be adjusted in the Training Options section of the NOS Pro Application. This adjustment will reduce the number of shots recorded that are simply a product of slow trigger release (set heavier to avoid false triggers). There is also an option to limit rounds to x shots, which would reduce the issues in post-processing data.
- Ensure that extra shots per firing set are recorded in a paper log in order to assist with the post-processing of the data.
- Provide initial training on the difference between controlled pair shots versus a double-tap.
- Consider the strength of the equipment's Bluetooth antennae, or consider a Bluetooth booster in order to maintain real-time monitoring of shot data. If signal is not strong enough, the FN expert optical unit will store shot data and send it upon reconnection, but will reduce the researcher's ability to monitor extra or missed shots.
- When utilizing this methodology in the field, try to use ruggedized equipment (laptop, weapons, etc.) as exposure to elements such as dirt and rain may become an issue. Additionally, minimize the amount of oil used on the weapon when testing in the field as it was found that the dirt mixed with the oil and reduced the operations of the weapon.
- When setting up the course, consider a north/south direction for the firing lanes, keeping the sun from being directly behind the targets. The sun was behind some targets in the early morning during testing, creating a variability in glare.

- Consider the ground type (sand density) when using multiple firing lanes, ensuring that it is consistent across the lanes. In between trials, consider raking the sand for the sake of consistency.
- Ensure that the CO2 chamber is filled prior to the start of each portion of this task to avoid mid-task weapon failure. The chamber typically handles 200 shots on one fill, but environmental conditions can significantly reduce the total shots. Use of a different fill gas may increase the number of shots obtained on a single fill (i.e. nitrogen).
- Ensure extra supplies are available in order to reduce impact on testing (e.g. spare o-rings, extra CO2 tank, extra hose/fittings, extra batteries for CCO units).
- Ensure FN Expert optical units are fully charged at the start of each day. Charging during the day will cause them to drop Bluetooth connection, and requires reinitiating the program in order to re- "pair" the connection. This may cause delays in testing if not timed correctly.
- Consider doing the dynamic task before the One Target task, particularly on the post-test in order to fully capture the fatigue effects.
- Consider expansion on the qualification process in order to rank the test participants' abilities and account for any potential learning/familiarization effects during testing. The current task simply utilized a qualification process with the intention of simulator system familiarization.

3.3 Foot March

3.3.1 Foot March Background

3.3.1.1. Measuring Biomechanical Performance During a Foot March

Much of the research related to Soldier load carriage has involved quantification of the effects of external loads on energy consumption, with the rate of oxygen uptake ($\dot{V}O2$) used as an indicator of energy consumption (Knapik, Harman, & Reynolds, 1996). There are few studies in which biomechanical measures have been recorded in association with prolonged bouts of load carrying. Gait data were acquired in a study conducted by Frykman, Harman, Knapik, & Han (1994), but only at the beginning and the end of a period of load carrying. Furthermore, no studies have been carried out in which physiological and biomechanical responses to prolonged load carrying have been recorded simultaneously in a field setting. Increasing the load weight changes the kinematics and muscle response of the human body during locomotion. In terms of body kinematics, studies have shown that increases in backpack weight result in increases in the forward inclination of the trunk (Harman, Han, Frykman, & Pandolf, 2000; Martin & Nelson, 1986). Martin and Nelson examined the effects of load weight on spatial and temporal gait variables and demonstrated that, with an increase in pack load, both men and women had a higher step rate, shorter stride length, shorter swing time, and increased double support time. The literature also suggests that, in addition to the negative weight effects, ballistic protective equipment encumbers or restricts body movements, further contributing to negative effects on physical performance (Hasselquist, Bensel, Corner, & Gregorczyk, 2012).

The U.S. Army field manual (FM 21-18) on foot marches suggests that the commander considers all factors that will affect marches and selects a rate that will place the unit at its destination in the

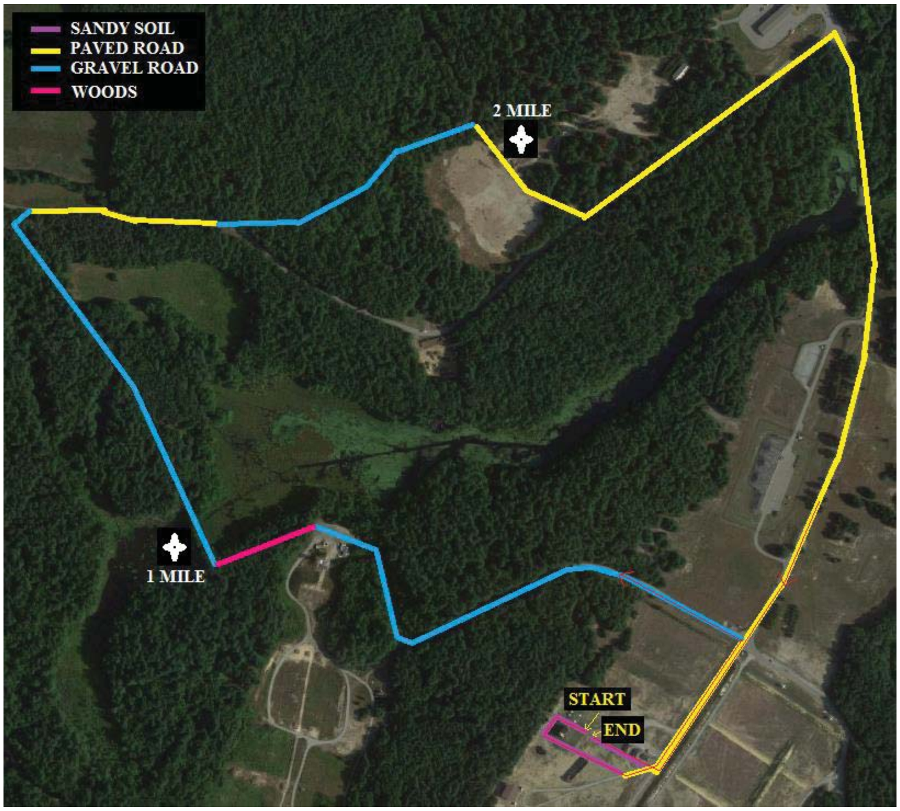
shortest time at combat ready condition. Rates for marches over varied terrain are usually prescribed at a rate of 2.5 mph. (Department of the Army, 1990). Research suggests that a pace of 3 mph is an efficient pace for walking with loads to find kinematic and cognitive response changes (Eddy et al., 2015). This value is within the range identified by Saltin and Stenberg (1964) as being an efficient rate for walking with a load that represents 40 to 50% of body weight. Further, Patton et al. (1991) included 3 mph as one of the three velocities tested in their study of prolonged walking on a level surface. Statistically significant increases in VO_2 were obtained when loads of 31.5 or 49.4 kg were carried at this velocity. The biomechanical data in this methodology utilized IMUs and HR GPS watches for data collection in a field environment to quantify and examine these negative effects.

3.3.1.2. Measuring Cognitive Performance Under Physical Exertion

Previous work examining the effect of physically fatiguing exercise on cognitive performance has been mixed (Chang, Labban, Gapin, & Etnier, 2012; Lambourne & Tomporowski, 2010; Paas & Adam, 1991; Tomporowski, 2003; and Tomporowski & Ellis, 1986). However, previous laboratory work aimed at characterizing the effects of CIE and load has shown decrements in performance on a response inhibition task, reliant on frontal cortex, when walking with a load (40 kg) compared to walking with no load for 2 h (Eddy et al., 2015). Specifically, with increased physical load, more errors were made on a response inhibition task (go, no-go task). In the methodology described here, the go/no-go response inhibition task has been modified to be used in an operational scenario on the road march. Given the strong findings in the laboratory and some pilot work in the field, this task was expected to show sensitivity to decrements in cognitive performance across CIE.

3.3.2 Foot March Task Setup

The foot march route (Figure 4) was planned to require the participants to traverse over a variety of terrains and grades. This design perceptually challenged the participants while they were marching due to the varied terrain and grades. This was an important aspect of the march and enhanced the importance of the cognitive performance task. The terrain that the participants marched on consisted of paved, sand, dirt, gravel roads, and forest path. The varied grades of ascent and descent were no greater than +/-5% at any section of the course. The selected pace of 3 mph for the foot march with load was determined by the researchers to be a sufficient pace over the varied course terrain to elicit biomechanical and cognitive response differences in the participants across equipment conditions (Eddy et al., 2015). This distance and pace was chosen to reduce the risk of injury and attrition from the study. The foot march was designed to be challenging, but not so difficult that participants could not complete the march.



Note: The start and end were located at the same point, and the 1-mile and 2-mile marks are displayed. The path terrain type is indicated by the path color.

Figure 4. Diagram of Foot March Route.

3.3.3. Foot March Training

3.3.3.1. Foot March Physical Performance Task

Participants practiced their pacing on the 3-mile, 3-mph march on the pre-determined course. Prior to individually practicing the pacing, all participants walked the course as a group with a member of the study staff to familiarize themselves with the route. The practice march exposed the participants to the distance, terrain, and grades they would later experience on the course and allowed for practice at maintaining pace. Signs at each quarter mile provided participants with information on the distance they had traveled and at what time they should be reaching that point. The participants also practiced the march individually, without a study staff member, a single time in Condition I prior to the experiment.

3.3.3.2. Foot March Cognitive Performance Task

Participants were given an opportunity to practice the auditory task during the orientation sessions. Participants practiced the auditory task until they felt comfortable performing the task and were familiar with how to properly use the response device. A study team member confirmed each participant was performing the task properly.

3.3.4. Description of Foot March Task

3.3.4.1. Foot March Physical Performance Task

The foot march consisted of a 3-mile, paced approach march. Participants began at the road march station where a large timing clock was kept to ensure individual participant departures at 20 min intervals. Before each departure, participants were equipped with either a rucksack or small backpack, in-ear headphones that were attached to the tablet carried in their pack, the hand-held USB response device, and a weighted mock M4. In test conditions with a load, an assault pack was worn during the march and a small backpack was worn when a condition other than a baseline and no load condition was utilized. Just before starting the march, an IMU trigger event was added using the extra pocket IMU and the GPS watch was initiated. During the march, participants monitored their 3-mph speed with GPS watches. Sign posts at every quarter mile provided distance and time checks. Study team members were stationed at checkpoints at each mile mark, making sure the participants were on pace and addressing equipment/participant issues as necessary. Participants completed the march loop at the foot march station; had another IMU trigger event added; had the GPS watch stopped; and doffed the MOLLE pack or tablet pack, mock weapon, headphones, and response device.

3.3.4.2. Foot March Cognitive Performance Task

Participants wore in-ear noise-cancelling headphones (M4 Electronics) and carried a Samsung Slate 7 tablet that was placed in the MOLLE pack in the two loaded equipment conditions and in a small backpack in the no equipment condition. Note that if the CIE evaluation does not involve rucksacks in the baseline condition, then a small backpack that can accommodate a tablet should be worn to hold the tablet during the foot march task. However, addition of a loaded rucksack is suggested in order to increase fatigue levels during the road march and to simulate conditions similar to what Soldiers encounter during an approach march. Any tablet operating with software ports can be utilized with this testing protocol. A USB response device consisting of a single button was held in the participant's dominant hand.

Participants performed an auditory "go"/"no-go" task during the foot march. For this task, participants were presented with AK-47 and M4 gunfire sounds through the headphones. The task required participants to respond to AK-47 but not M4 gunfire using the response device. This task was performed for 5 min at a time, with short breaks in between. This "go"/"no-go" task had a frequent "go" stimulus (AK-47) that set up a pre-potent response (i.e., one that is difficult to withhold) by having a large proportion of "go" trials and relatively few "no-go" trials (M4). In other words, participants anticipated "go" trials, thereby making it difficult to inhibit responding to "no-go" trials. This experimental design probed response inhibition, a task very relevant for Soldiers in operational contexts. The ratio of "go" to "no-go" tasks was 80% "go" and 20% "no-go".

The transient hypofrontality hypothesis (Dietrich, 2003) suggests that there are decreases in frontal neural activity due to the demands of exercise that lead to decrements in cognitive processes reliant on frontal brain regions, such as executive control. In addition, previous work found that during load carriage compared to not carrying a load, decrements in performance are observed on this

task (Eddy et al., 2015). An auditory version of the task was chosen given its field portability (i.e., participants are responding to auditory rather than visual stimuli, allowing for stimulus presentation to occur as participants move through the march) and has been shown to be sensitive to load effects in a previous lab study (Eddy et al., 2015).

During the two foot march portions of the scenario, participants performed this audio task approximately every 10 min starting at the beginning of walking. Each participant performed the task five times during each foot march at the following time intervals: 0-5 min; 15-20 min; 30-35 min; 45-50 min; 55-60 min. A 5-min segment of the task contained 125 trials, for a total of 625 trials for each foot march. This task can be adjusted to have varying break lengths. The "go"/"no-go" task measures executive control and requires sustained attention and constant monitoring for the "no-go" stimulus.

3.3.5. Discussion of Lessons Learned From Foot March Task

3.3.5.1. Foot March Physical Performance Task

- Consistent pacing was an important component of the task. Even though pace was emphasized, practiced, participant self-checked at each 1/4 mile, and additionally researcher checked at 1-mile and 2-mile points, it was difficult to keep the participants on the exact prescribed pace. It was observed in a minority of the participants that when in the unloaded condition, the participant wanted to go faster than prescribed; in the loaded conditions, the participant had difficulty maintaining the prescribed pace due to fatigue. If research personnel are available, then each participant could be paced on the course by the researcher. However, this becomes logistically challenging depending on the number of participants. Advancement in GPS and wrist-worn monitor technology may give the researcher additional pacing control mechanisms without having participant interference during the foot march and related cognitive tasks.
- Ensure that all devices are fully charged and operational each day. The participant was able to manipulate the watch timing device and in a small number of circumstances inadvertently stopped and started the GPS watch. A back up timing system and spotters at 1 and 2 miles were used for overall completion time to account for these errors.

3.3.5.2. Foot March Cognitive Performance Task

- The previous points about pacing are important for the timing of the cognitive task to ensure participants are encountering the same terrain each time they perform the task in different equipment configurations. Slight variations in the pacing are acceptable. However, walking too slowly or too quickly can lead to performance of the task at the wrong point on the foot march. Additionally, the wrong pace can alter the fatigue state of the individual and does not allow for control of march pace while holding constant time at which the task is performed (e.g., someone walking too slowly will be less fatigued at minute 45 compared to someone walking at the correct pace or too fast).
- It is important to consider equipment failures and how to best deal with these technical issues during the course of the foot march. For the current study, the study team positioned back-up equipment at each checkpoint. But there will always be circumstances that cannot

be planned for during a field study when utilizing electronics for data collection. The study team tested and charged tablets, response devices, and headphones every morning to ensure the response devices were working properly and that the audio was playing at the appropriate volume. In addition, because of the field test conditions, the study team cleaned the response devices with isopropyl alcohol at the end of each day (and on humid days, in between the foot marches) to lessen the likelihood of buttons sticking.

- Properly securing the tablet in the rucksack is important, as there were a few instances where participants adjusted the pack by leaning forward, pulling the pack up, and allowing the tablet to fall out. From that point forward, the team used bungee cords to secure the opening (necessary for air flow around the tablet and for audio and response devices wires). The response device USB was taped to the tablet to minimize risk of it being pulled out when participants readjusted the rucksacks.

3.4 LEAP Obstacle Course

3.4.1 LEAP Background

The LEAP system (HumanSystems, Inc., Guelph, ON Canada) was originally developed by the U.S. Marine Corps as a way to assess the effect on human performance due to CIE being worn. The obstacle course that was used as part of this study was only one segment of the LEAP course, which also included a vertical jump, vertical and horizontal load transfer task, and a marksmanship task. Timed runs of obstacle courses, which require such activities as jumping, crawling, climbing, and balancing, have been used extensively in studies to evaluate different designs of load-carriage equipment (Brainerd & Bruno, 1985; LaFiandra et al., 2003), the effects of weight on performance (Batty, Coyne, DeSimone, Mitchell & Bensel, 2016; Mitchell et al., 2016), and the effects of changes in CIE (Tack, Kelly, Richter, & Bray-Miners, 2012; Bray-Miners & Kelly, 2012; Brewster, 2014; Dutton & Stryker, 2015). A combined obstacle and MOUT course have been used in previous studies of load carriage equipment. Hasselquist et al. (2013) tested rucksacks varying in prototype design and found that course completion times were sensitive to differences in weight on the body when comparing a medium rucksack to no rucksack, but not pack design. LaFiandra et al. (2003) examined differences in obstacle and MOUT course times for three load-carriage systems that were approximately equal in weight and had similar centers of mass (COMs). Findings from previous research have also shown that training is required to perform consistently on an obstacle course and up to three 100% effort trials are required to negate training effects (Sharp et al., 2009, Mitchell et al., 2017).

3.4.2. LEAP Setup

All the obstacles in the LEAP are designed to duplicate standard Warfighter tasks. The 10 obstacles in the LEAP are completed in sequence with no rest breaks and consist of the following: tunnel and hatch crawl through, straight ahead sprinting run, stair and ladder negotiating, zig-zag agility run, casualty drag, two window traversals, a series of four bounding rushes, balance beam traversal, low crawl maneuver, and two walls to maneuver over (Figure 5). Descriptions of each of these obstacles can be found in Appendix B.

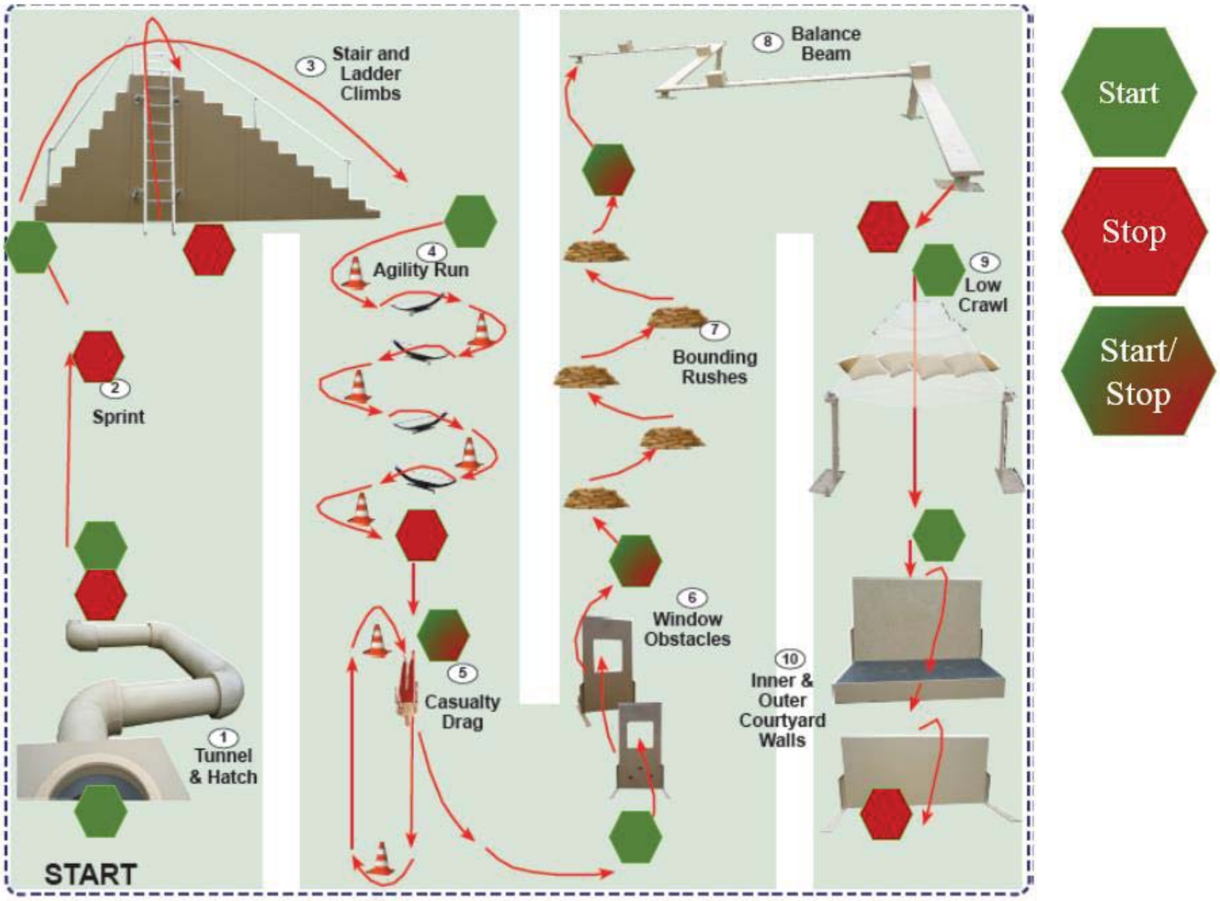


Figure 5. Layout of LEAP Obstacles.

3.4.3. LEAP Training

Participants completed a walkthrough of the LEAP obstacle course and were instructed on how to perform the individual obstacles properly by a member of the study team. The participants needed to execute the tasks/obstacles in the manner instructed each time the course was attempted. The participants were given the opportunity to practice individual key obstacles (e.g., windows, walls, balance beam, casualty drag, and stairs/ladder). Participants then completed two full course practice trials in Condition I, at a sub-maximal effort (50-75% max effort). Participants then completed three additional full course practice trials in Condition I two times and in Condition III one time, at a maximal effort. During the training sessions, participants were given rest time after the execution of the LEAP obstacle course. These training runs were completed across 2 days of testing. During these runs, a member of the study team followed them, correcting anything that did not match the instructions (e.g., when participants forgot to stop at the end or beginning of an obstacle or took multiple rungs of the ladder at one time).

3.4.4. Description of LEAP Task

Following the completion of the foot march, participants moved directly into the LEAP station. They brought their mock weapon from the foot march with them. Prior to starting the test, their HR GPS watch was started and participants were asked to provide a RPE. Participants then

told to “go” and they started the obstacle course. At the end of each obstacle, they came to a full stop. Figure 5 shows the locations of each stop (red hexagon) and start (green hexagon), as well as places where the start and stop are the same (red and green gradated hexagon). At each of these stops, participants were required to come to a full stop where their feet were planted on the ground and their torso did not sway. At this time, a data collector added an IMU trigger event marker with the extra pocket IMU. The stops were essential for the IMU post-processing algorithms to allow the calculations of obstacle-based performance metrics to adequately account for sensor drift over the obstacle durations. Once the participant had completed all the obstacles, their HR GPS watch was stopped, they gave an additional RPE, and they then rated their Mission Performance. The participant provided comments to the data collector regarding any difficulties they had performing the obstacles due to the equipment configuration. Following this discussion, the data collector took the participant’s weapon, and the participant moved directly to the MOUT building to start that task.

As the participant completed the obstacle course, a data collector used a stop watch to manually record the total time to complete the obstacle course. Also, each participant was videotaped going through the LEAP course as an additional back-up timing system.

Ideally, weather conditions should be dry when navigating the LEAP course, but a light mist is acceptable; however, obstacles should be wiped dry before participants traverse them, especially the stairs/ladder, windows, balance beam, and walls.

3.4.5. Discussion of Lessons Learned From LEAP Task

- It was difficult for participants to become accustomed to the starting and stopping after each individual obstacle. But they appeared to adjust nicely by the time data collection started. Therefore, the training implemented was a reasonable amount, although less obvious learning effects may still have been occurring. Overall, the training was sufficient for participants becoming familiar with the execution of the obstacles and because order of presentation was varied, any potential lingering learning effects would be masked. It is recommended that a strong training regimen be implemented as well as a varied order of presentation (randomization, quasi-randomization, counterbalance, etc. could potentially be used).
- Stop watch timing was not the same as the IMU timing, although the stop watch gave much more immediate data than that which are available from the IMUs. Video recording worked well as a backup for timing data, although a wide screen view is needed because display screens are not usable in the sunlight.
- While the IMU algorithms used in this study required the participants to stop after each obstacle to account for sensor drift over time, future algorithms may eliminate this necessity. Such a change would allow participants to traverse the course without interruptions between obstacles while maintaining obstacle-specific biomechanical data accuracy and validity.
- For ease of data analysis, study team members were required to mark the data via a manual clicker at each of the obstacle start and completion times. Improvements in technology and obstacle/movement recognition algorithms would aid in this process and eliminate the need. However, during this evaluation, it was required. It was difficult to maintain strict

consistency of the data collectors making the physical mark in the IMU data with the manual clicker. However, extensive practicing appeared sufficient, although no analysis of inter- or intra-measurer consistency/reliability was conducted. Once participants no longer need to stop between obstacles (to account for drift), the ease and consistency of a tester marking the data should be re-assessed.

- The locations of the current starts and stops on the course were assigned to best match the traditional locations of the timing gate system on the LEAP. That system is designed to incorporate transition times between each of the obstacles. However, with the use of the IMUs for timing, it would reduce the burden to the participant and testers if starts and stops were combined as frequently as possible and if they were reduced. To a limited degree, this was done for this assessment. For example, the ladder and stair obstacle was captured as one obstacle as opposed to capturing each stair set and ladder as a unique obstacle. Additionally, the two windows were merged and the two walls were merged into one obstacle.
- The crawl obstacle was modified from the traditional LEAP task, which consists of a low crawl, a supine crawl, and a high crawl. For this test, only a high crawl was utilized due to concerns regarding displacement of the IMUs mounted on the boot laces. Ideally, additional investigation into IMU placement and attachment methods should be done to allow for completion of the course as intended.
- During the course of LEAP obstacles, most participants knocked their HR GPS watch at some point, turning the recorder off. It was unclear which particular obstacles caused this to occur. Alternative HR GPS systems should be investigated that would not be so easily activated. Alternately, some type of protection system should be added to the current HR GPS watch.
- When moisture is in the air, the obstacles should be continually wiped down to ensure they are dry and safe for participants when they maneuver through them.
- It is recommended that participants be restricted from using smokeless tobacco or gum while going through the LEAP course for safety reasons.
- Participants completed the LEAP immediately after completing the road march. Some participants reported numbness in their hands/arms due to rucksack paralysis. It is recommended that a question be added to the methodology to identify any potential safety concerns prior to execution of the course.

3.5. MOUT

3.5.1. MOUT Background

Global urbanization and international securities have made combat engagements in the urban environment more prevalent. The ability to move through and clear buildings in cities has become a critical mission performance task and essential to evaluating CIE. The MOUT facility used for this particular study provides a simple, two-story building that simulates those found in current theaters of operation. Typically, these facilities are used to conduct dismounted Soldier close combat training, but they have not often been used for marksmanship performance in simulated close quarter combat under sleep deprivation conditions (McLellan et al., 2005; Clemente-Suarez & Robles-Perez, 2015). Nor have they been used for target detection and identification under various types of physiological strain (Tikuisis, 2006). Further, close combat and urban building

clearing in combination with marksmanship and the cognitive skill of decision making has not been utilized for evaluating the effects of CIE on performance. In this event, the Soldiers were required to clear the MOUT building, using short-range marksmanship skills, to eliminate threatening targets throughout the facility.

Section 3.2 provides additional information on the marksmanship task and weapon simulator background. In addition to the FN Expert marksmanship simulator system, shot timing data were collected utilizing a Double Alpha Academy (DAA) SHOTMAXX timer. This device is a competition timer that detects the sound and vibration of a shot, and records the time at which it occurred. In addition, the researcher used a shot recording program on a tablet to record the number of shots fired at each target. These data were used to verify the timing data and capture shots that missed the targets but were correctly executed based on the threat/no-threat determination.

3.5.2. MOUT Setup

The equipment needed for this task was as follows: 14 P38 prism reflectors and HIB modules and stands, a FN sensor, a weapon, a handheld tablet with Bluetooth capabilities and the NOS Pro application for FN data recording, a SHOTMAXX timer, a GoPro Camera, a shot counter program, pictures of threating and non-threatening objects placed on targets, and a building with multiple rooms for clearing (see Appendix E). Note that paper and pencil is also an acceptable method for counting shots, but the shot counter program allows for quick and accurate recording during fast-paced clearing. Also note that an open room with dividing walls could be set up in lieu of a multiple-room building for this task.

At the beginning of each day, the MOUT facility was set up with targets in locations based on the scenario day target sequence plan (see Appendix C for details). In addition, the NOS Pro FN software application was opened, ensuring that the correct position of the optical unit was selected and connected via Bluetooth. For this study, the optic was mounted on the right side of the barrel using the Picatinny rail. Then, the FN Expert optical unit was mounted on the weapon and aligned with the weapon's sighting system (the use of a parallax-free system, such as the Close Combat Optical unit M-68, is recommended as it will reduce the time required for software zeroing). Once the FN Expert optical unit was mounted on the weapon, the weapon was placed in a gun vise and aligned such that the sights were aimed at the center of a target. The optical unit was mechanically adjusted following the FN Expert User's Guide instructions, such that the optical unit was aiming at the center of the reflector ring when the sights were aimed at the center of the target. This is the same set-up as was used for the dynamic marksmanship task

Finally, the SHOTMAXX watch was set up in order to ensure use of the accelerometer instead of the microphone to record shots from airsoft type weapons. In addition, the delay for the timer was set to 3 s to allow the participant to get into position to start the task.

3.5.3. MOUT Training

3.5.3.1. MOUT Marksmanship Performance Task

Training for the MOUT involved a complete walkthrough of the MOUT course and a practice room clearing trial with the threat determination task. First, participants were shown the correct path to take through the MOUT as well as the indicators of out of bounds areas by a member of the study team. During this walk through, no targets or markings of target locations were present because the goal was solely to familiarize the participants with the route to take through the building. Participants executed the tasks in the same manner instructed each time the course was attempted. Participants also completed two practice trials in both a baseline condition and in an equipped condition (i.e., Condition I and in Condition II), at a sub-maximal effort (50-75% max effort), in a different part of the building to avoid developing familiarity with target locations. The targets used threat/non-threat pictures that would not be used in the actual scenario in order to prevent familiarity. After each training period, the study team discussed any clearing issues and concerns with the participant that should be corrected prior to the data collection.

3.5.3.2. MOUT Cognitive Performance Task

For the MOUT scenario, participants were briefed on the task, how the shoot/don't shoot task would proceed, and then practiced acquiring targets in a mock-up of the testing condition (see MOUT Training below for more details). Prior to practice, participants were briefed on what were considered threatening ("shoot") items and what were considered non-threatening ("don't shoot") items. The training session did not take place in the same rooms as the actual scenario testing, and the "shoot"/"don't shoot" objects placed on targets were different from the objects used in the actual testing scenario.

3.5.4. Description of MOUT Task

3.5.4.1. MOUT Marksmanship Performance Task

The MOUT Marksmanship task consisted of firing at scaled E-type silhouette targets, incorporating FN Expert specific P38 prism reflectors and HIB modules. These targets were located throughout the MOUT complex (see Appendix C for examples), and the participants were asked to engage the targets with the FN Expert weapon simulator. The targets were marked as threatening or non-threatening by a picture of an object attached to the target.

When each participant arrived at the MOUT building, they were fitted with a GoPro camera on their helmet and a SHOTMAXX timer watch on their dominant wrist with their sleeve rolled up. The FN Expert optical unit was paired with the NOS Pro application on a handheld tablet, and the participant was asked to shoot a single shot at the target to ensure system alignment and to start the recording process. Next, the participant was asked their RPE. Finally, prior to start, the researcher initiated the shot counting program on the tablet and started the wrist-worn HR monitor.

A target was placed outside of the building and used to mark the onset of the trial. The SHOTMAXX timer was set and gave a tone to indicate to the participant when to start. Participants

were asked to clear the rooms as they had been trained, as if they were the lead member of a fire team, shooting the threatening targets with controlled pairs. For ease of flow, they were instructed not to enter spaces marked off limits and not to clear behind open doors. The researcher followed the participant throughout the event, marking the number of shots fired using the tablet program. Upon completion of the task, the researcher stopped the HR monitor, removed the GoPro camera, stopped the NOS Pro application, and stopped the SHOTMAXX timer to avoid erroneous recordings. Finally, the participant was asked their RPE score and Mission Performance score. Upon completion of this task, the participant was sent to the foot march station to complete their second march.

3.5.4.2. MOUT Cognitive Performance Task

The MOUT scenario was completed in sequence with no rest breaks and included hallways, rooms, and stairs. During the MOUT portion of the scenario, cognitive performance was measured on a “shoot”/“don’t shoot” decision-making task while decision accuracy and reaction time measures were collected. This task mirrored the cognitive processes in the auditory “go”/“no-go” task during the foot march. The “shoot”/“don’t shoot” task measured decision accuracy on shooting at targets placed within the MOUT environment using the FN Expert weapon simulator system. Participants were briefed on which targets were threats (i.e., targets that should be shot) and those that were non-threatening (i.e., targets that should not be shot) during the orientation session and prior to completing testing. Some examples of threatening objects on the targets were as follows: pistol, machine gun, and bomb. Some examples of non-threatening objects on the targets were as follows: soda can, stapler, spatula. For the shooting decision task, the location and types of targets were different each time the participant completed the task across the three test conditions. A GoPro camera mounted to the helmet of the participant served as a back-up for scoring decision accuracy. In total, there were 12 targets consisting of 9 “go” trials and 3 “no-go” trials. The order and location of these targets were randomized across test days so participants did not learn sequences or target locations. In addition, different threatening/non-threatening items were used across the test days and were counterbalanced across participants.

3.5.5. Discussion of Lessons Learned From MOUT Task

The MOUT task had several lessons learned and included the following:

- The SHOTMAXX timer’s accelerometer was very sensitive to bumps and hits, resulting in occasional false shot detection. More accurate recordings were achieved when placing the timer on the dominant shooting wrist rather than the non-dominant wrist as recommended in the SHOTMAXX manual. In addition, removing any clothing or items that may interfere or touch the device improved the accuracy (e.g., the participants should keep their sleeve rolled up for the scenario’s entirety).
- Some of the participants wore sunglasses and had a hard time with initial eye adaptation to the dark interior of the MOUT during practice. Removing any eyewear prior to entry is recommended.
- P38 prism reflectors and HIB modules required two AA batteries. Changing these batteries every couple of weeks to ensure working equipment is recommended.

- The M4 was filled with CO2 at the beginning of the day and at least once more during the test to ensure that the rifle expelled enough pressure for the accelerometer and application to correctly identify shot data.
- The M-68 CCO sighting system or similar system was not necessary for shooting at targets within the MOUT due to their close proximity.
- Four systems of recording the shot data were utilized during this study (FN Expert software, SHOTMAXX, shot counting program, and GoPro video). This may seem redundant, but it was required for seamless data processing.
- Due to the close proximity to the targets, the FN Expert software application did not record some data. With the shot counting program, the SHOTMAXX timer output, and the backup GoPro video recordings, targets were determined to either have been "missed" or not recorded rather than attributing the decision made to not shoot to the threatening/non-threatening nature of the target. However, it was not possible to determine whether the participant actually missed the target, or if the program simply did not record the data. A bigger site with larger rooms that allow for the targets to be placed at a greater distance would help alleviate this problem. Another possible solution would be to use a different target type, such as the DG ring or a combination of ring and prism with a greater placement spread across the target. This may increase the rate of hit captured by the software. Further development of this methodology will address this issue.
- This study required individual soldier building clearing in order to capture individual performance. Training in building clearing without a team is essential and was provided during the practice runs prior to testing. During the training, it is very important to stress that each participant should consistently clear the building using similar techniques each time they run the scenario.
- Ensure clarity in the pictures of the non-threating versus threatening objects. There were some items used in this study that were unintentionally confusing and were interpreted as either threatening or non-threatening to the participant based on their personal experience. In future iterations of this task, participants should be briefed and familiarized with all of the possible objects prior to the study to ensure they understand which ones constitute threatening and non-threatening targets.
- There was some initial confusion as to the placement of the pictures above the target's COM. The participants were unsure whether to shoot at the target's center or at the threatening picture. This could affect the accuracy and probability of hit/probability of lethal hit measures. Ensure that this is addressed in the training prior to the initial testing day.

3.6. End of Day Tasks

At the end of the day, participants removed all their sensors. The biomechanical data were downloaded from the IMUs and saved into designated files for future analysis. The IMUs were then charged for the next day. The participants' HR data were downloaded from the Garmin 220 HR Monitor into data files within the Garmin computer software. In addition the participants completed an end of day human factors questionnaire. The equipment used for this task was tablet based surveys. Soldiers were addressed by the research principal investigators to identify any

concerns or injuries after the day's tasks. Participants were reminded of the requirements for proper nutrition and sleep.

4. DISCUSSION AND CONCLUSION

The U.S. Army continually seeks to improve the CIE used to outfit and protect the individual Soldier. This improvement is accomplished by assessing the acceptability of next-generation or novel protective equipment, as well as of field clothing, through limited user evaluations of the candidate items. The results of these assessments have consisted mainly of subjective data in the form of participants' comments and opinions after performing simulated mission activities. While previous qualitative assessments have gleaned useful information, they have been limited in how they have investigated the quantitative effects of the test items on Soldier performance of relevant military activities. Further, laboratory studies provide a rich literature on cognitive and physical performance under conditions of load carriage that simulate some of the mission-relevant tasks Soldiers are asked to perform. However, there is additionally a need to assess equipment in a more operationally relevant context. Lastly, there is a need to create and validate a reliable and operationally relevant test bed for assessing the impact of CIE on Soldier physical, physiological, biomechanical, cognitive, and subjective task performance.

Therefore, the objective of this study was to establish a test methodology utilizing an operational scenario for assessing the effects of CIE on Soldier physical and cognitive performance. This objective was accomplished by translating established scientifically based cognitive and physical metrics (which are sensitive to changes in CIE/fatigue) into an integrated, repeatable, field test battery that supports the methodology development. The scenario was designed to have Soldiers perform an operationally relevant and fatiguing set of tasks (e.g., movement to an objective, action on an objective, etc.). Scientists from the NSRDEC Biomechanics and Engineering, Cognitive Science, and Human Factors Teams have established common measures of performance in the form of a Soldier-relevant field test methodology. The methodology included controlled foot marches, LEAP-A obstacles, and a weapon simulator for marksmanship. A MOUT course was also be included within the mission scenario.

Military operations entail missions in various terrains. Therefore, a foot march to and from an objective can be considered common within Soldier mission scenarios. The foot march distance, pace, and CIE conditions used in this evaluation were established in previous NSRDEC laboratory testing and have produced relevant and reliable biomechanics, physiologic, and cognitive measures (Eddy et al., 2015). By moving to the field setting, the study team was able to utilize established laboratory methods in a realistic Soldier environment. Test conditions in this scenario included varied terrain designed to physically challenge the Soldier while traversing open space and wooded paths, inclusive of paved, dirt, and gravel roadways. The two foot marches in this scenario utilized a research-established pace, CIE configuration and exertion level, which afforded NSRDEC researchers the ability to collect biomechanical, physiological, and cognitive data while physically tasking the Soldier at different levels of exertion.

Timed runs of obstacle courses, which required activities such as jumping, crawling, climbing, and balancing, have been used extensively in studies to evaluate different designs of load carriage equipment (Brainerd & Bruno, 1985; LaFiandra et al., 2003). This methodology utilized an established obstacle course (LEAP-A) that was designed to mimic relevant Soldier tasks and physically challenge the Soldier at maximum effort. All of the obstacles were developed from Soldier and Marine experiences in theater and represent challenging tasks encountered in

warfighting situations. The study team has established the use of these LEAP-A obstacles as a means to discern CIE equipment performance differences in a controlled field setting. Timed runs of this obstacle course required activities of jumping, crawling, climbing, and balancing, and were used extensively in this study to evaluate different CIE conditions. A secondary goal of using the LEAP-A obstacle traversal was to challenge the Soldier with a maximal exertion task within the scenario. This enabled the team to physically fatigue the individual Soldier at a set point in the scenario and then evaluate changes in the Soldier's biomechanical, physiological, and cognitive metrics during the MOUT, secondary foot march, and secondary marksmanship tasks.

In past studies, MOUT courses have been used independently and in combination with obstacle courses to evaluate specific Soldier-relevant tasks and Soldier CIE/PPE effects on physical and cognitive performance (Hasselquist et al., 2013; LaFiandra et al., 2003). The use of the designed MOUT course within this scenario established a Soldier-relevant task that mimics the clearing of a building while making cognitive choices during Soldier engagement with targets. Unique to sequencing the MOUT task within the scenario events was the use of the LEAP-A obstacle course to physically fatigue the Soldiers and place them under physical duress before they were required to enter the MOUT course, engage targets, and make cognitive decisions.

It can be argued that marksmanship is the most important task for the warfighter to master. Thus, understanding the complex physical and cognitive effects of CIE on the Soldier and physical exertion effects on marksmanship are of the utmost importance. Further, a fundamental capability of the Soldier is their ability to optimize marksmanship under a variety of conditions, weapons, and postures. The study team's decision to use marksmanship as its Soldier performance outcome task is well established in previous research. The weapon simulator system utilized in this methodology has been used and techniques verified in several NSRDEC studies (Baca et al., 2012; Hawkins & Sefton, 2011; Tharion et al., 2003; Warber et al., 2002). Development of a test methodology using the FN Expert Weapon Simulator for CIE testing has been underway for several years. McNamara et al. (2016) developed a five-target methodology that focused on the timing required for target engagement across the vertical and horizontal plane from a static location, providing additional information on aiming, transition, and engagement times. In this current study, the dynamic marksmanship task builds upon the five-target method, providing a more active scenario that captures the entire target acquisition and engagement sequence (Brown, McNamara, & Mitchell, (in press)). The study team uniquely utilized marksmanship within the scenario to achieve several goals. Organizing the methodology to have marksmanship as the book-ending task of the scenario allowed the measurement of the effects of CIE during dynamic and static marksmanship while being rested and physically fatigued. Additionally, this methodology utilized marksmanship within the scenario in combination with cognitive tasks while under physical stress in a MOUT environment.

The scientific equipment and analysis techniques that are detailed in this report have been applied previously to determine Soldier physical, cognitive, and physiological performance (e.g., IMUs, "go"/"no-go" cognitive tasks, %HRR) and have been verified in a controlled laboratory environment and field settings (Fox, Davidson, McGinnis, Saunders, & McLean, 2014). Scientists from the NSRDEC Cognitive Science Team have recently established mobile cognitive tasks that allow cognitive performance to be measured *during* physically fatiguing tasks, as opposed to after, when recovery from the decrements of physical fatigue on cognition happen quickly and do not

allow for a true assessment of the impact of physical exertion on cognitive processes. The establishment of new methods and measures to explore the effects of CIE on cognitive processes and performance have been explored as a task concurrent to physical task performance in controlled independent laboratory and field tests (Eddy et al., 2015). The scientific research techniques and equipment developed for this methodology are based on a mixture of controlled laboratory and field environment assessments that have been run independently in previous research and are specifically structured to inform acquisition decision makers on the performance of CIE.

The presentation, order, and use of these equipment and techniques in a field setting within the scenario are unique. The research techniques described in this report have established a progression of NSRDEC's ability to move from the laboratory assessments to high quality quantitative field research. The study team has shown that the use of this methodology can be an important tool for the evaluation CIE effects on Soldiers' biomechanical, physiological and cognitive metrics. This methodology goes beyond the typical CIE evaluation techniques of past research. By combining physical stressors, Soldier-relevant tasks, cognitive and biomechanical measures, and unique equipment over a realistic evaluation period, NSRDEC has developed a distinct methodology to evaluate CIE.

The methodology described in this report has employed a comprehensive set of assessment tools to address the challenges of Soldier performance research in field environments. These are as outlined in Table 3.

Table 3. Comprehensive Assessment Measures.

Biomechanical	Physiological	Physical Performance	Cognitive	Human Factors
Temporal, Kinematics, PCA	Heart Rate, Heart Rate Reserve (HRR), $VO_{2\ peak}$, Fatigue	Marksmanship Reaction Time and Accuracy, Time to Complete LEAP-A	Response Inhibition, Marksmanship Judgement, Decision Making	Fit/Sizing, Perceived Exertion, Basic Movements, Pain, Discomfort, User opinions and acceptability of test items

This methodology gives a complete picture of what challenges Soldiers may experience during complex scenarios. This research formulates and employs an evaluation methodology that establishes measurable standards for assessing Soldier performance in the next generation of CIE. A follow-on Part II of this report will address the specific results and analysis from the implementation of the methodology described in this report.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 18/004 in a series of reports approved for publication.

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APPENDIX A

Example Questionnaires and Data Sheets

14-021 DEMOGRAPHICS QUESTIONNAIRE

TP ID: _______ Date: _________

Demographics

1. Rank:______________________ (e.g., E-3, WO-4, 0-2)
2. Gender: ◯ Male ◯ Female
3. Which ethnic/racial group do you most identify with?

◯ White, not Hispanic ◯ Black, not Hispanic ◯ Hispanic
◯ Asian/Pacific Islander ◯ Native American
◯ Mixed (specify): _________________
◯ Other (specify):_________________
◯ Don't Know/Prefer Not to Answer

4. MOS: __________________ (Primary) (e.g., 11B) Description: ______________________ (e.g., Infantry)
5. Age: ____________ Years
6. Time in service: _________ Years
7. Number of combat tours: ________
8. When did you return from you last deployment: ____________ (mm/yyyy)
9. Combat tour location? ◯ Iraq ◯ Afghanistan ◯ Other
10. Glasses/contact lenses: ◯ Yes, glasses ◯ Yes, contact lenses ◯ No
11. Which hand do you write with? ◯ Left ◯ Right
12. Which is your preferred shooting eye: ◯ Left ◯ Right
13. Which leg do you prefer to kick a ball with? ◯ Left ◯ Right

Health and Exercise History

14. Do you smoke tobacco and/or electronic-cigarettes? ◯ Yes ◯ No

If yes, how many times per day? _____ times/day

15. Do you chew tobacco? ◯ Yes ◯ No If yes, how many times per day? _____ times/day
16. Do you drink/ingest caffeine? ◯ Yes ◯ No

If yes, how many servings per day? Coffee _____ Soda ________ Energy Drinks______ Other: __________

17. During the course of a normal week in garrison, how much time do you spend performing the following activities?

Cardiovascular	_______ hrs/day	_______days/week
Weight lifting	_______ hrs/day	_______days/week
Playing sports	_______ hrs/day	_______days/week
Watching tv/movies	_______ hrs/day	_______days/week
Playing video games	_______ hrs/day	_______days/week

14-021 DEMOGRAPHICS QUESTIONNAIRE

TP ID: _______ Date: _________

18. What was your most recent PT score? _______ of 300 Test date: ________

2 mile run time: ____ min ____ sec Push Ups: _______ Sit Ups: ________

Clothing and Equipment Experience

19. During your most recent deployment, which body armor vest did you wear (or if never deployed or not deployed within the past 2 years, what is your current body armor vest system):

○ OTV (front opening) ○ IOTV (over head/ shoulder opening) ○ SPCS (plate carrier) ○ Other:_______________

20. Current body armor size worn:

○ X-Small ○ Small ○ Medium ○ Large ○ X-Large ○ ≥ 2 XL ○ Other

○ Med Long ○ Large Long ○ XL Long

21. Which hard armor plates do you typically wear? (select all that apply) ○ None ○ Front ○ Back ○ Sides

22. Do you typically wear any of the add-on components? (select all that apply)

○ Collar/Neck/Yoke ○ Groin ○ Shoulder ○ Extremity armor (arms) ○ Extremity armor (legs)

23. During deployments, please estimate the number of hours per day you spend wearing your armored vest?

○ Never deployed or __________ hrs/day

24. What weapon do you typically carry during deployment/training for dismounted patrol type activities?

○ M4 ○ M16 ○ SAW ○ Other: ____________

25. What was your last rifle marksmanship qualification score? ________ of 40

26. What is the weight (estimated) of a typical load you carry during deployment/training for dismounted patrol type activities? ________ lbs

27. Please specify the quantity of the equipment that you typically carry on your body with you on dismounted patrols in a deployment/training environment:

Qty	Item	Qty	Item
____	Hygiene Kit	____	IR Chems
____	Improved First Aid Kit (IFAK)	____	Multipurpose tool
____	Night vision device, with batteries (specify _______________)	____	Infrared Strobe, small
____	Strap cutter	____	Body armor
____	Hydration system (100 oz), with water	____	ESAPI plates (front, back)
____	Tactical Assault Panel (TAP)	____	Helmet
____	Spectacles	____	Goggles
____	Magazines	____	Water canteen (1 qt), with water
____	HE Rounds	____	Frag Grenades
____	Smoke Grenades	____	Other ammunition (specify_______________)

14-021 DEMOGRAPHICS QUESTIONNAIRE

TP ID: _______ Date: _________

____ Batteries (specify ________________) ____ Radio (specify ______________________)

____ Other (specify ______________________) ____ Other (specify ______________________)

____ Other (specify ______________________) ____ Other (specify ______________________)

Injury History

28. Have you ever had an accident/injury that required surgery to repair? ◯ Yes ◯ No
    If yes, what was the year of the injury and what surgery was required:

    Yr: ________ Surgery:____

Have you ever in your life had an accident to one or more body part, which caused you to seek medical attention, change your daily activities or miss school or work for multiple days? If yes, please specify the year the injury occurred, the most recent injury and if it required surgery to correct. Examples of types of injuries are (broken bones, sprains, stress fractures, torn cartilage/ligaments, tendinitis, etc.)

Body Part	Yes	No	Surgery required	Year of injury	Injury Name
Head	Y	N	Y	_______	____________________
Neck	Y	N	Y	_______	____________________
Upper Back	Y	N	Y	_______	____________________
Lower Back	Y	N	Y	_______	____________________
Shoulder	Y	N	Y	_______	____________________
Arm	Y	N	Y	_______	____________________
Elbow	Y	N	Y	_______	____________________
Wrist	Y	N	Y	_______	____________________
Hip	Y	N	Y	_______	____________________
Upper Leg	Y	N	Y	_______	____________________
Knee	Y	N	Y	_______	____________________
Lower Leg	Y	N	Y	_______	____________________
Ankle	Y	N	Y	_______	____________________
Foot	Y	N	Y	_______	____________________

14-021 DEMOGRAPHICS QUESTIONNAIRE

TP ID: _______ Date: _________

To Be Completed by Tester

Fit and Sizing

Body Weight :_____________ lb

Stature :_____________ mm

Crotch Height :_____________ mm

Chest Circumference :_____________ mm

Head Length :_____________ mm

Head Breadth :_____________ mm

Head Circumference :_____________ mm

Males Only	1st	2nd	3rd	Average
Neck Circumference	:_______ mm	:_______ mm	:_______ mm	:_______ mm
Waist Circumference (OM)	:_______ mm	:_______ mm	:_______ mm	:_______ mm

Females Only	1st	2nd	3rd	Average
Neck Circumference	:_______ mm	:_______ mm	:_______ mm	:_______ mm
Waist Circumference (NI)	:_______ mm	:_______ mm	:_______ mm	:_______ mm
Buttock Circumference	:_______ mm	:_______ mm	:_______ mm	:_______ mm

ACH best fit size: X S M L X

SPCS Size Predicted: X S M L X

Size	**XS**	**Small**	**Medium**	**Large**	**XL**
mm	737-838	838-940	940-1041	1041-1143	1143-1245
Inches	29-33	33-37	37-41	41-45	45-49

ACH Helmet Size Prediction Chart			
Helmet Shell Size	***Head Length inches(mm)***	***Head Breadth Inches(mm)***	***Head Circumference Inches(mm)***
Small	***<7.25 (<184)***	***<6.50 (<162)***	***<21.25 (<538)***
Medium	***7.25-7.75 (184-198)***		***21.25-22.50 (538-573)***
Large	***7.75-8.25 (198-210)***		***22.50-23.50 (573-597)***
X-Large	***>8.25 (>210)***	***>6.50 (>162)***	***>23.50 (597)***

14-021: PRE-TEST STATUS DATA SHEET

TP ID #:_________ Date:__________ Test Configuration:____________

1. Did you eat breakfast (if in morning group) /lunch (if in afternoon group)? ◯ Yes ◯ No

a) How long ago did you last eat? _____ hrs

b) What did you eat at your last meal? ________________________

2. How would you rate the quality of sleep you received last night?

Very Poor	Poor	Neither Poor nor Good	Good	Very Good
◯	◯	◯	◯	◯

a) How many hours sleep did you get last night?_________________________

3. Have you consumed alcohol in the past 24 hrs? ◯ Yes ◯ No

a) If yes, how long ago? ________hrs

4. Other than as part of this test, have you participated in moderate-heavy exercise in the past 24 hrs?

◯ Yes ◯ No

a) If yes, please describe the exercise performed, including how long ago it was performed, type of exercise, and duration of exercise

____

____

____

____

5. Have you injured yourself in any way since you left our last test session? ◯ Yes ◯ No

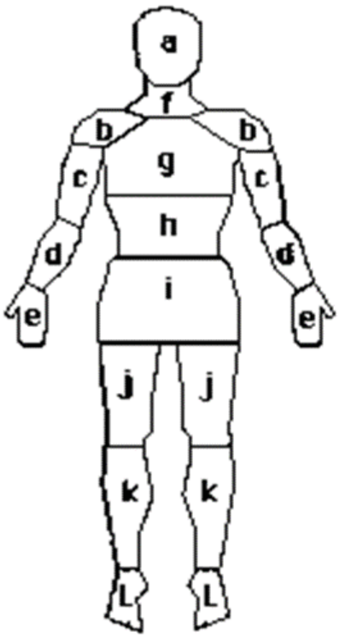
b) If so, where (on the body)?____

c) If so, how did you injure yourself?____

14-021: PRE-TEST STATUS DATA SHEET

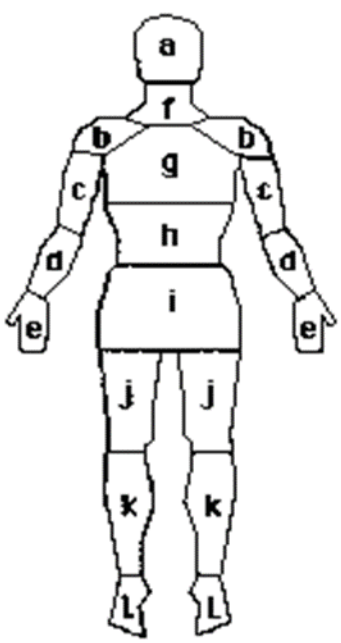
TP ID #:_________ Date:__________ Test Configuration:____________

6. Rate the degree of PAIN, SORENESS, or DISCOMFORT that you are currently feeling for Body Parts A through L. Do so for the FRONT and the BACK of the body.



FRONT of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐



BACK of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

14-021: Main Event Data Sheet: MARKSMANSHIP 1

Evaluator:_________ **Date:**__________

Rating of Perceived Exertion														
No Exertion at all	Extremely Light		Very Light		Light		Somewhat Hard		Hard (Heavy)		Very Hard		Extremely Hard	Maximal Effort
6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Mission Performance Ratings						
Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good
1	2	3	4	5	6	7

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				

14-021: Main Event Data Sheet: MARKSMANSHIP 1

Evaluator:_________ Date:__________

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				

14-021: Main Event Data Sheet: FOOT MOVEMENT 1

Evaluator:_________ **Date:**__________

Rating of Perceived Exertion														
No Exertion at all	Extremely Light		Very Light		Light		Somewhat Hard		Hard (Heavy)		Very Hard		Extremely Hard	Maximal Effort
6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Mission Performance Ratings						
Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good
1	2	3	4	5	6	7

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				

14-021: Main Event Data Sheet: FOOT MOVEMENT 1

Evaluator:_________ **Date:**__________

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				

14-021: Main Event Data Sheet: LEAP (O-Course)

Evaluator:_________ Date:___________

Rating of Perceived Exertion														
No Exertion at all	Extremely Light		Very Light		Light		Somewhat Hard		Hard (Heavy)		Very Hard		Extremely Hard	Maximal Effort
6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Mission Performance Ratings						
Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good
1	2	3	4	5	6	7

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: ___________			Pre: Post:	1---2---3---4---5---6---7
Configuration: ______________				
TP: ___________			Pre: Post:	1---2---3---4---5---6---7
Configuration: ______________				
TP: ___________			Pre: Post:	1---2---3---4---5---6---7
Configuration: ______________				
TP: ___________			Pre: Post:	1---2---3---4---5---6---7
Configuration: ______________				

14-021: Main Event Data Sheet: LEAP (O-Course)

US ARMY NATICK SOLDIER RD&E CENTER

Evaluator:_________ **Date:**__________

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				

14-021: Main Event Data Sheet: MOUT

Evaluator:_________ Date:__________

Rating of Perceived Exertion														
No Exertion at all	Extremely Light		Very Light		Light		Somewhat Hard		Hard (Heavy)		Very Hard		Extremely Hard	Maximal Effort
6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Mission Performance Ratings						
Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good
1	2	3	4	5	6	7

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				

14-021: Main Event Data Sheet: MOUT

Evaluator:_________ Date:__________

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				

14-021: Main Event Data Sheet: FOOT MOVEMENT 2

Evaluator:_________ **Date:**__________

Rating of Perceived Exertion														
No Exertion at all	Extremely Light		Very Light		Light		Somewhat Hard		Hard (Heavy)		Very Hard		Extremely Hard	Maximal Effort
6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Mission Performance Ratings						
Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good
1	2	3	4	5	6	7

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				

14-021: Main Event Data Sheet: FOOT MOVEMENT 2

Evaluator:_________ Date:__________

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				
TP: __________			Pre: Post:	**1---2---3---4---5---6---7**
Configuration: _____________				

14-021: Main Event Data Sheet: MARKSMANSHIP 2

Evaluator:_________ **Date:**__________

Rating of Perceived Exertion														
No Exertion at all	Extremely Light		Very Light		Light		Somewhat Hard		Hard (Heavy)		Very Hard		Extremely Hard	Maximal Effort
6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Mission Performance Ratings						
Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good
1	2	3	4	5	6	7

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				

14-021: Main Event Data Sheet: MARKSMANSHIP 2

Evaluator:_________ Date:__________

	Start Time	Finish Time	RPE (6 through 20)	Mission Performance (1 through 7)
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				
TP: __________			Pre: Post:	1---2---3---4---5---6---7
Configuration: _____________				

After completing all shots in a firing position, the participant was asked to rate the degree of Interference/Degradation experienced from the equipment while performing that task using the 5-point rating scale shown below.

Subjective Interference Rating Scale

No Interference	Slight Interference	Moderate Interference	Severe Interference	Extreme Interference
1	2	3	4	5

14-021: End of Daily Activities Questionnaire

TP ID #:_________ Date:__________ Test Configuration:____________

Please rate the following attributes **as impacted by the Test Ensemble that you wore today**, using the rating scales below. Fill in only one number for each and choose N/A if you cannot answer for a particular attribute. Please explain any rating ≤ 4 in the space provided below each set of questions.

1. EASE OF DONNING (putting items on):	Very Difficult	Moderately Difficult	Slightly Difficult	Neither Difficult nor Easy	Slightly Easy	Moderately Easy	Very Easy	N/A
a. Donning Body Armor Vest	1	2	3	4	5	6	7	X
b. Donning Ancillary Armor	1	2	3	4	5	6	7	X
c. Donning other mission gear (helmet, pouches, backpack, knee/elbow pads, etc.)	1	2	3	4	5	6	7	X

Please explain any answer ≤ 4

2. FIT	Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good	N/A
a. Rate the Overall Fit of the configuration	1	2	3	4	5	6	7	X

Please explain any answer ≤ 4

3. PHYSICAL COMFORT (resulting from pressure points, skin irritations, bulkiness, pinching, etc.)	Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good	N/A
a. Rate the Physical Comfort of the body armor configuration	1	2	3	4	5	6	7	X

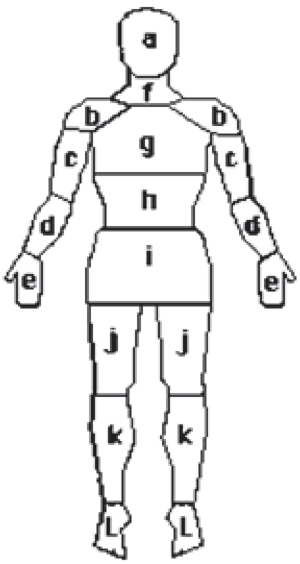
Please explain any answer ≤ 4

14-021: End of Daily Activities Questionnaire

TP ID #:_________ Date:__________ Test Configuration:____________

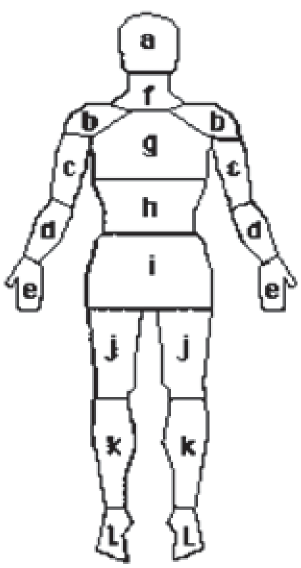
4. DISCOMFORT

Please rate the degree of **PAIN**, **SORENESS**, or **DISCOMFORT** that you are currently feeling for Body Parts A through L. Do so for the FRONT and the BACK of the body



FRONT of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐



BACK of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

a. What type of discomfort it was (pain, pressure, soreness, chaffing, pinching, hot spots, etc.)

b. What caused the discomfort, could it be alleviated?

14-021: End of Daily Activities Questionnaire

TP ID #:_________ Date:__________ Test Configuration:____________

5. COMPATIBILITY (the ability to wear/use items together as intended, with no or minimal negative impacts):	Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good	N/A
a. Compatibility of body armor configuration and **helmet**	1	2	3	4	5	6	7	X
b. Compatibility of body armor configuration and **Load Carriage Equipment**	1	2	3	4	5	6	7	X
c. Compatibility of body armor configuration and **other** item of equipment Other: ____________	1	2	3	4	5	6	7	X

Please explain any answer ≤ 4

6. MISSION PERFORMANCE, as impacted by the test ensemble	Very Poor	Moderately Poor	Slightly Poor	Neither Poor nor Good	Slightly Good	Moderately Good	Very Good	N/A
a. Overall ability to accomplish Mission Critical tasks and movements effectively	1	2	3	4	5	6	7	X
b. Ability to freely move head/neck	1	2	3	4	5	6	7	X
c. Ability to freely move arms	1	2	3	4	5	6	7	X
d. Ability to freely bend/turn at the waist	1	2	3	4	5	6	7	X
e. Ability to freely move legs	1	2	3	4	5	6	7	X
f. Ability to aim/sight weapon – **Standing Unsupported**	1	2	3	4	5	6	7	X
g. Ability to aim/sight weapon – **Kneeling Unsupported**	1	2	3	4	5	6	7	X
h. Ability to aim/sight weapon – **Prone Unsupported**	1	2	3	4	5	6	7	X
i. Other: ______________	1	2	3	4	5	6	7	X

Please explain any answer ≤ 4

14-021: End of Daily Activities Questionnaire

TP ID #:_________ Date:__________ Test Configuration:____________

7.	**ACCEPTABILITY/SUITABILITY for Mission Use**	**Very** Unacceptable	**Moderately** Unacceptable	**Slightly** Unacceptable	**Neither** Unacceptable **nor** Acceptable	**Slightly** Acceptable	**Moderately** Acceptable	**Very** Acceptable	**N/A**
a.	Overall Acceptability of the body armor configuration for use in a combat environment	1	2	3	4	5	6	7	X

Please list any recommended modifications or improvements:

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APPENDIX B

LEAP Obstacle Course Description and SOP Instructions

Appendix B.

LEAP Obstacle Course Description and SOP Instructions

Tunnel and Hatch

The soldier approaches the stair portion of the tunnel and hatch obstacle (refer to Figure 1) and climbs up the stairs one step at a time. The soldier then lowers him/herself (feet first) into the hatch opening (refer to Figure 2).

Figure 1. Stairs on the Tunnel and Hatch Obstacle.

Figure 2. Hatch Opening.

Next, the soldier lowers him/herself into a crouch position and enters the opening of the tunnel (Figure 3) on all fours. The soldier will continue traversing through the tunnel until s/he emerges out the other end. Upon completing the length of the tunnel, the soldier quickly returns to a standing position and runs towards the start of the sprint.

Figure 3. Opening of the Tunnel.

Sprint

After emerging from the tunnel obstacle, the soldier passes by the timing light sensor, which also signifies the start of the sprint segment. The soldier sprints at his/her fastest capable running speed for 20 yards (18.3 m). The sprint ends when the second sensor is passed.

Stairs and Ladder

Upon passing the timing light sensor, the soldier will run to the stair and ladder obstacle. The soldier must progress through this obstacle in the following order:

1) climb up the high rise stairs
2) climb down the low rise stairs
3) climb up low rise stairs
4) climb down high rise stairs
5) run to the base of the straight ladder
6) climb up straight ladder
7) climb down angled ladder
8) climb up the angled ladder
9) climb down the straight ladder

The soldier finishes this segment of the obstacle course by passing by the timing light at the bottom of the straight ladder.

Agility Run

After passing by the initial sensor for this segment, the soldier must run towards the first flag (as shown in Figure 4), then make a tight cut around the outside of the flag and head back in the opposite direction towards the second flag, jumping over a hurdle obstacle along the way. This continues for the set of five (5) flags and five (5) hurdles that are set up in the formation shown in Figure), and this segment is complete when the soldier passes by the timing light sensor after the fifth hurdle.

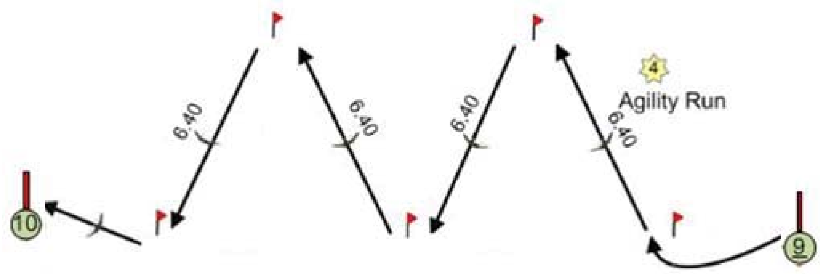


Figure 4. Agility Run.

Casualty Drag

For the casualty drag portion of the obstacle course, the Soldier will drag a "Rescue Randy" mannequin (similar to Figure 5, but without the lower legs) out to a turn-around point and back to the original position at which the mannequin was located. Note that "Rescue Randy" wears a body armor (usually the Improved Outer Tactical Vest (IOTV)) and the bottom portion of his legs are removed.

Figure 5. Rescue Randy (a) stock image and (b) as utilized for LEAP testing.

The order shall be as noted in Figure 6, whereby the soldier crosses the starting timing light sensor (1) then runs to the casualty mannequin and lifts it up into a drag position (2). The soldier crosses the first timing light sensor (3) then drags the mannequin out towards the far flag (4) continues around the outside of the flag (5) and heads back toward the close flag (6). The soldier then rounds the close flag (7) and returns the mannequin to its original position (2) before running towards the next timing light sensor (8).

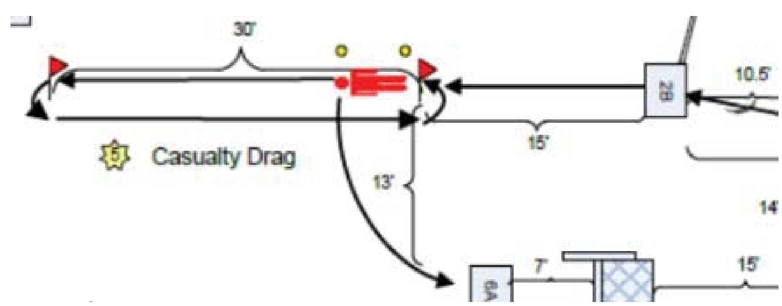
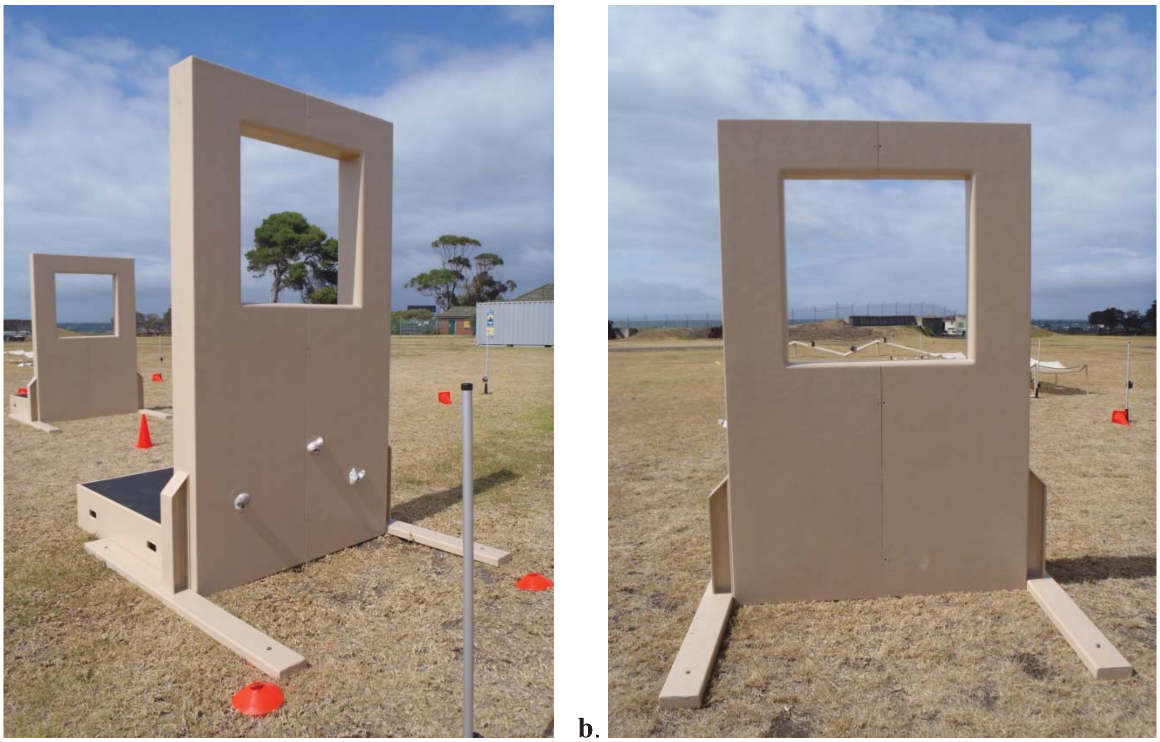


Figure 6. Casualty Drag.

Window Obstacle

To complete the window obstacles, the soldier must first go through the window opening of Window 1 (shown on left (a) in Figure 7). The soldier is free to choose whether or not to use toe holds for assistance when climbing up the wall. After landing on the platform, the soldier runs to Window 2 (shown on the right (b) in Figure) and climbs through the window opening.



a. **b**.

Figure 7. Window Obstacles.

For the purposes of safety, the soldier must land on their feet on the landing platform (as opposed to diving or rolling through the window opening). This segment of the obstacle course is complete when the soldier passes by the timing light sensor after the second window obstacle.

Bounding Rushes

The soldier begins the bounding rushes segment by passing by the timing light sensor and running to the first pile of sandbags. Upon arriving at the first set of sandbags, the soldier drops into the prone position and takes a sight picture, and then leaps up to a running position. The soldier then sprints to the next (staggered) pile of sandbags and assumes another prone position. This cycle repeats until all piles of sandbags have been reached, and the segment ends when the soldier passes by the timing light sensor.

Balance Beam

For the balance beam obstacle, the soldier keeps to the outside of the line of cones (refer to Figure 8) and steps up on to the beam from the end. Jumping up onto the beam from the side is not permitted. The soldier carefully walks across the balance beam while stepping over the box-shaped obstacles. Stepping on top of the box obstacle is not permitted. The soldier must exit the balance beam by stepping off the end (not the side) and then keeping to the outside of the line of cones, running towards the next sensor.

Figure 8. Traversing the Balance Beam.

High Crawl

When completing the crawl obstacle, the soldier begins by crossing the timing light sensor, and then completes a high crawl as fast as s/he can. At both the 10 and 20 foot marks (3 m and 6.1 m), there will be a row of sandbags, over which the soldier must crawl. After exiting from the end of the crawl obstacle, the soldier runs to the next timing light sensor, thus completing this obstacle.

Inner and Outer Courtyard Walls

The wall obstacle is comprised of an inner and outer courtyard wall set in a staggered formation. The soldier begins by traversing over the outer courtyard wall (shown in Figure 9a) as quickly as possible. Any manner of traversing is permitted, and the soldier may use the foot holds for assistance. After traversing the outer courtyard wall, the soldier sprints to the inner courtyard wall (shown in Figure 9b) and crosses over it as fast as possible. To complete this segment (and the timed course), the soldier runs past the final timing light sensor.

a.  **b.** 

Figure 9. Outer(a) and Inner(b) Courtyard Walls.

14-021 LEAP Obstacle Course SOP Instructions:

1. Complete segment of data sheet with TP ID, configuration and approximate start time of task.
2. TP will travel to table from Road March segment.
3. Tester will walk TP to the start point of the course.
4. TP will be given these instructions:
    a. You should complete this course following operationally accurate tactics at your maximal effort. Prior to each obstacle, stand completely still until your data collector tells you to continue.
5. Ask TP to rate their Borg RPE (6-20) rating.
    a. Record Rating on data sheet
6. Tester will start the video camera and show the board (or verbally speak) with the following information displayed:
    a. TP ID number
    b. Configuration
    c. Date and Test Day
7. Ensure Biomech Tester is ready to start.
8. Biomech Tester will tell TP to "go".
    a. As the tester says "go" and the TP starts, the stopwatch should be started.
9. Tester should follow TP through course videotaping TP
    a. Stay out of the TP's way, walking in the aisles of the course.
    b. Ensure video camera captures as TP passes the "start" and "end" points of each obstacle clearly.
10. As the TP completes the course, stop the stopwatch.
11. Ask TP to again rate their Borg RPE (6-20) rating.
12. Ask TP to rate their Mission Performance (1-7) rating.
13. Stop the video camera.
    a. Record Ratings on data sheet.
14. Walk with TP over to MOUT site and transition individual to MOUT test personnel
    a. Record any comments TP made about equipment, ability to go through the course, and note if there were any actions that may have delayed their time (e.g., fell off balance beam). This annotating can be done while walking and prepping for MOUT, or after TP is dropped off.
15. Tester returns to LEAP test table and prepares for next TP.

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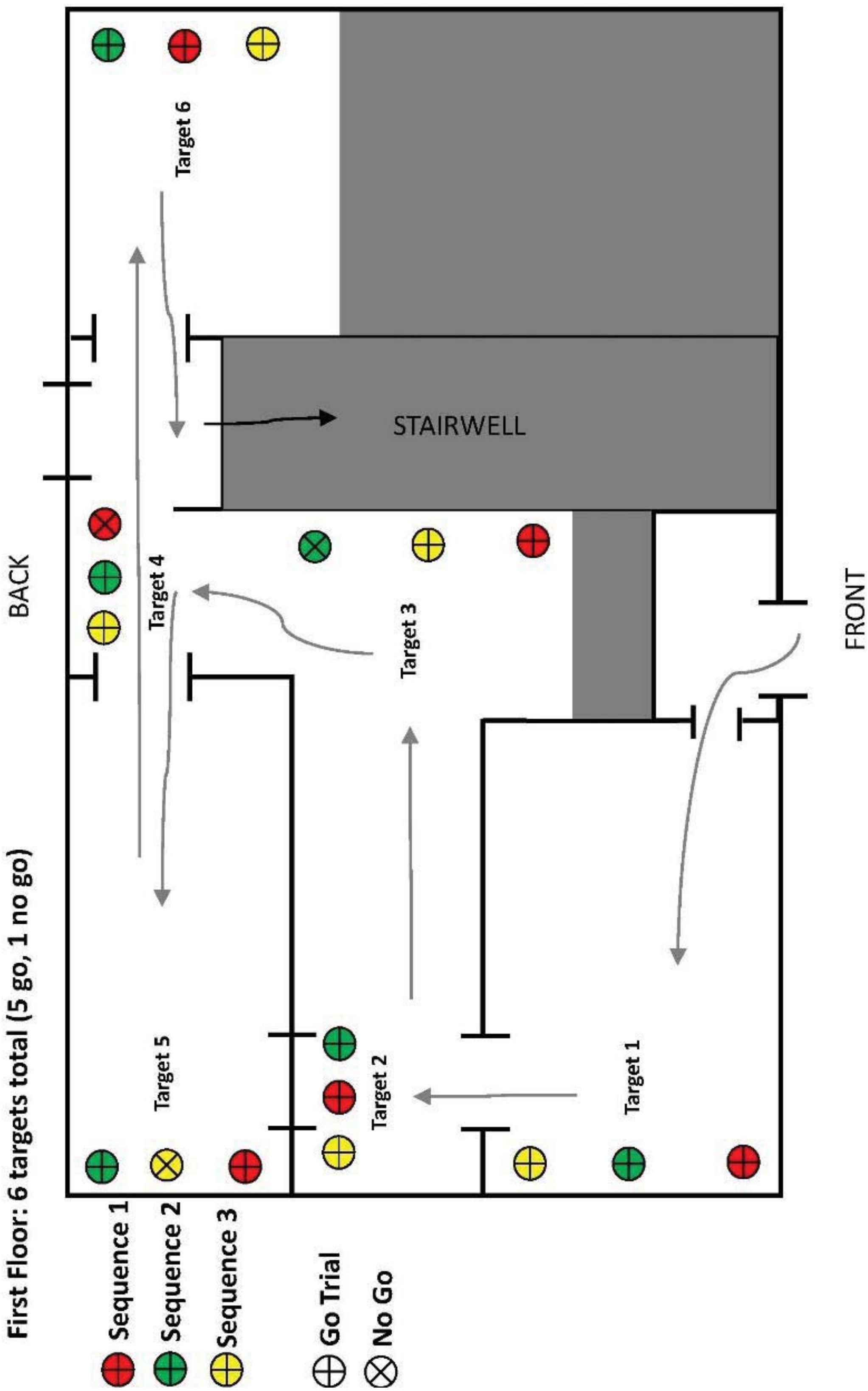
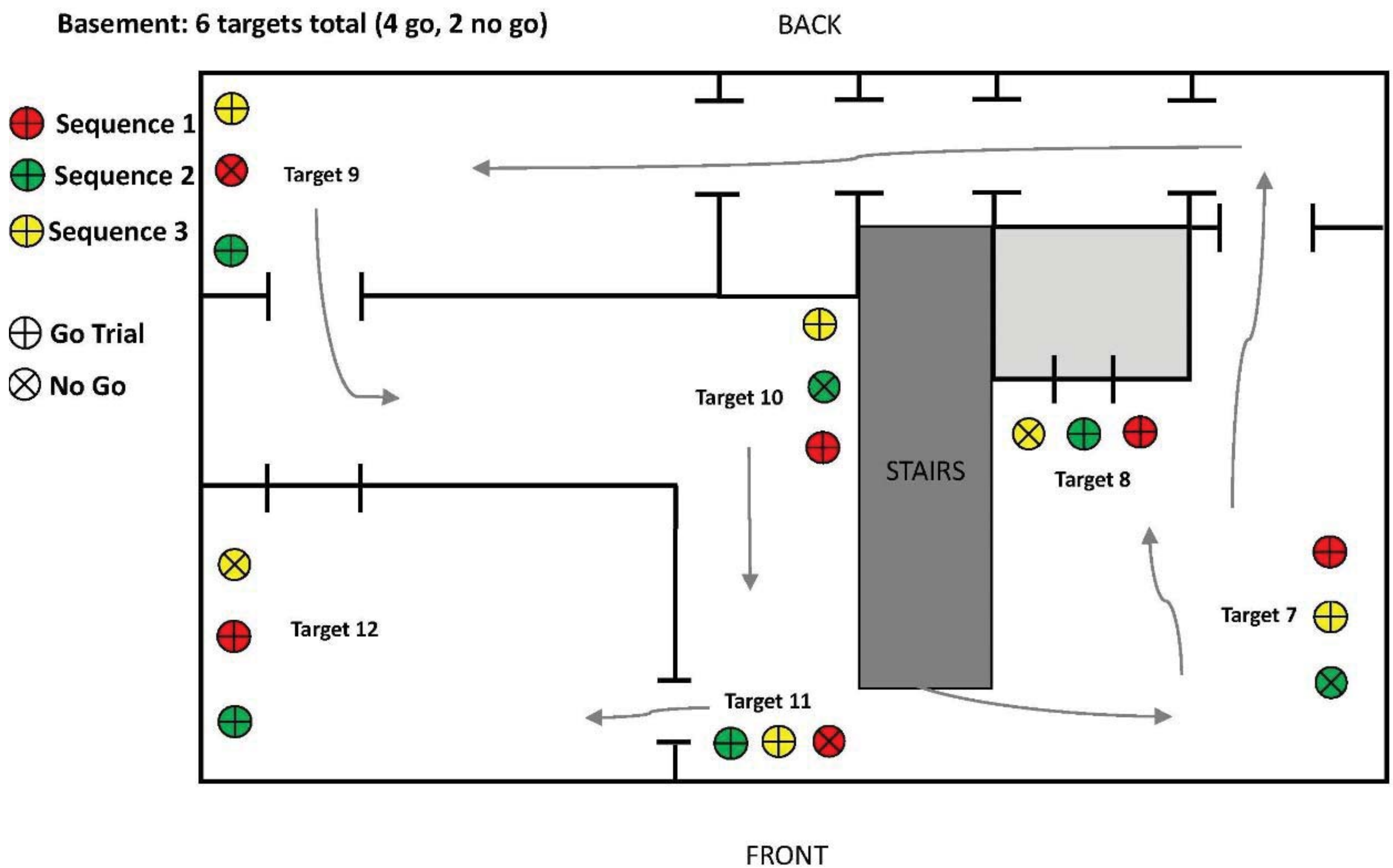
APPENDIX C

Example Targets and Locations for MOUT Task


First Floor: 6 targets total (5 go, 1 no go)
BACK
FRONT
STAIRWELL
Target 1
Target 2
Target 3
Target 4
Target 5
Target 6
Sequence 1
Sequence 2
Sequence 3
Go Trial
No Go


Basement: 6 targets total (4 go, 2 no go)
BACK
Sequence 1
Sequence 2
Sequence 3
Go Trial
No Go
Target 9
Target 10
Target 8
STAIRS
Target 7
Target 12
Target 11
FRONT

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APPENDIX D

Example Station Checklists

Test Day X - Group X RESTED						Marksmanship Checklist	
TP ID	Condition	Order	1 Target Code	Dynamic Code			Start Hr Monitor
							Pre-RPE rating
						Checklist	Collect Noptel Data
							record restriction rating arter each Firing position
							Post-RPE rating and Comments
							Stop Hr Monitor
						1 Target	5 Series or 5 Shots (25 total) in each Firing position
							2 shots in each target, 8 total shots per trial.
						Dynamic	1 trial per Firing position
							rest 30 seconds between trials
Test Day X - Group X FATIGUED							
TP ID	Condition	Order	1 Target Code	Dynamic Code			

ROADMARCH SCORING
TEST DAY

ROADMARCH # 1

Cond	TP	RPE Post	Mission Performance Post
BAPL 3			
BAPL 5			
BAPL 0			
BAPL 5			
BAPL 0			
BAPL 3			
BAPL 3			
BAPL 5			
BAPL 0			
BAPL 5			
BAPL 0			
BAPL 3			

ROADMARCH # 2

Cond	TP	RPE Post	Mission Performance Post
BAPL 3			
BAPL 5			
BAPL 0			
BAPL 5			
BAPL 0			
BAPL 3			
BAPL 3			
BAPL 5			
BAPL 0			
BAPL 5			
BAPL 0			
BAPL 3			

14-21 Ft. Devens Study – CHECKPOINT TABLET TROUBLESHOOTING

START OF DAY CHECKLIST:

- ☐ Backup response device
- ☐ Backup tablet

WHEN PARTICIPANT IS APPROACHING CHECKPOINT:

- ☐ Thumbs up means not doing task
  - **You can talk to participant**
  - Give feedback on pace
  - Offer water
- ☐ Hand up means stop, doing task
  - **You CANNOT talk to participant**
  - Give feedback on pace via whiteboard
  - Offer water
- ☐ Record cumulative clock time that come through checkpoint
- ☐ Radio time into road march start person

PROBLEMS THAT MAY COME UP:

Note, you will need to walk along with Soldier to try and fix issue since we want to keep them on schedule

- ☐ **Not hearing anything (troubleshoot in this order):**
  1. Check if headphones came unplug
  2. Pull tablet out while walking behind Soldier.

     If program has frozen or exited:
     - Unlock tablet, by hitting 1 – 2 – 3 – 4 – 5 – 6, then hit end task
     - Restart task, entering all information entered previously (on back of tablet)
       - **Checkpoint 1 restart and enter # blocks = 3**
       - **Checkpoint 2 restart and enter # blocks = 1**
  - **If this doesn't resolve the issue then replace tablet with backup**

  It may not be practical to deal with the issue, if it is slowing them down too much or too disruptive, don't keep trying to troubleshoot

  Make note of issue and when occurred.

END OF ROADMARCH

- ☐ Return tablet, response device to road march start
- ☐ Report on issues that occurred at checkpoint

14-21 Ft. Devens Study – CHECKLIST FOR ROAD MARCH (COG PORTION)

START OF DAY CHECKLIST:

- ☐ Tablets on table, labeled by participant number
- ☐ Tablets plugged in and charging
- ☐ Headphones labeled by participant next to correct tablet
- ☐ Response device plugged in and checked if working (open notepad, press button multiple times, ensuring 1 shows up for every button press)
- ☐ Check volume is set to specified level for participant (should be written on tablet on the tape)
- ☐ Set-up program with that days testing condition, road march # and participant information – **DO NOT START THE PROGRAM YET**
- ☐ Confirm delay between blocks is set to 480
- ☐ Obtain IMU time marker from biomechanics team
- ☐ Place IMU time marker in zip lock bag and secure with safety pin to shirt or pants
- ☐ Obtain RPE sheets from binder and secure to clipboard
- ☐ Set up white board with schedule

START OF ROADMARCH

- ☐ Have participant put in headphones, check they are secure, do not plug into tablet
- ☐ Remind participant of task, play practice sounds (on tablet labeled practice) if necessary (plug headphones into practice tablet)
- ☐ Start the testing program – **DO NOT HIT THE RESPONSE BUTTON**
  - ***If the button is pressed and the task starts, follow this procedure:***
    - Unlock tablet, by hitting 1 – 2 – 3 – 4, then hit end task
    - Restart task, entering all information entered previously
- ☐ Run response device through backpack handle, place tablet in outer MOLLE pouch
- ☐ Hand response device to participant (instruct them to not press button)
- ☐ Plug headphones into the tablet
- ☐ Tape response device and headphones to tablet
- ☐ Ask participant to give you a thumbs up once the march begins to let you know the task has started properly

☐ 2 minutes before the road march

1. Unlock watch

☐ 1 minute before the road march

1. Record participant's RPE

☐ 30 seconds before the road march

1. Insert IMU time marker into IMU
2. Press button on IMU time markers
3. Remove IMU time marker and replace to zip lock bag

☐ As soon as the road march begins they should
1. Hit the response button to start task
2. Hit the start button on the watch

☐ As soon as the road march begins they should
1. Hit the response button to start task
2. Hit the start button on the watch

☐ Watch for participant's thumbs up that task is working. If not, run after participant to ask.

END OF ROADMARCH

☐ Have participant remove headphones, drop pack, send participant to next task

☐ Record participant's RPE

☐ Record participant's performance assessment

☐ Insert IMU time marker into IMU, press button, and remove IMU time marker

☐ Remove tablet from backpack and place on table, plug in to charge

☐ Place response device, headphones next to participant's tablet ready for next use (follow set-up procedures above for entering condition, march # etc).

Test Day X - Group A			Target Sequence	MOUT Checklist
TP ID	Condition	MOUT Code		Pre-RPE Rating
				Place shotmaxx timer on strong hand wrist
				Place GoPro on Helmet
				Start Noptel Program
				TP Fires 1 Shot to ensure Noptel program is recording
				Start target scoring program
				Press start on shotmaxx timer
				TP fires a single shot at the target outside the bldg
				TP fires 2 shots at each threat target
				Remove shotmaxx watch
				Remove Go Pro
				Post-RPE Rating and Comments
				Record timer results by hand

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APPENDIX E

List of Test Equipment

The following is a list of test equipment needed to implement the operational scenario described in this report. Because we are documenting our (NSRDEC's) research approach for implementing the scenario, the equipment detailed below is specific to what we had available in house. This methodology and scenario are not limited to these specific equipment choices. Similar equipment/obstacles with reliable measurement capabilities, Soldier physical tasks, and Soldier relevant obstacles may also be used.

1. De-militarized M4 carbine with an integrated CO_2 recoil simulation system (LaserShot, Stafford, TX)
2. FN Expert Simulator System and portable computer. (Fabrique National (FN) America, McLean, VA USA)
3. FN Targets - : 5 DG sticker reflector paper ring targets (product number H-111, 10m scaled to 150m); 14 full size e-silhouette target board (NT-12) with four single P38 prism reflectors (K-101M) and hit indicator beam target module (NTM-10ER) mounted at the center of mass (101.6mm from left edge of torso, 508mm from bottom of torso) (Fabrique National (FN) America, McLean, VA USA)
4. Garmin Forerunner 220, GPS/Heart Rate Monitor (Garmin International, Inc., Olathe, KS USA)
5. Go/no-go task, NSRDEC Cognitive Science Team, Natick, MA USA
6. Hand Held USB Response Device, Delcom Products Inc., Danbury, CT USA.
7. In ear noise cancelling headphones (MX4 Electronics Inc., Timonium, MD USA)
8. Inertial Movement Unit (IMU) sensors, Opal Wearable Sensors, (APDM, Inc., Portland, OR USA)
9. LEAP Obstacle Course (HumanSystems, Inc., Guelph, Ontario Canada)
10. Manual Stop watches (generic)
11. Demilitarized M4 Weapon with CO_2 recoil conversion or similar mock weighted M4 Weapon (recoil conversion kit by LaserShot, Strafford, TX USA) (https://www.lasershot.com/law-enforcement/weapons/recoil-conversion-kits)
12. SHOTMAXX watch time (Double-Alpha Academy, Waalwijk, Netherlands)
13. Patrol Rifle Optic or similar optic to the M-68 red-dot close combat optic (CCO) (Aimpoint, Chantilly, VA USA)
14. Windows Tablet with audio and USB (full size) ports (Microsoft, Boston, MA USA)
15. GoPro Hero 3,(GoPro Inc., Riverside, CA USA)

Test Items Used in Specific Tasks.

Test Item	Task					
	Dynamic Marksmanship	Road March	LEAP	MOUT	Subjective and Set-up	Analysis
De-militarized M4 carbine with an integrated CO2 recoil simulation system	X			X		
Fabrique National Expert Simulator System and portable computer	X			X		
Fabrique National Targets	X			X		
Garmin GPS/Heart Rate Monitor	X	X	X	X	X	
Go/no-go task		X		X		
Hand Held Button, Delcom Products						
In ear noise cancelling headphones		X				
Inertial Movement Unit (IMU) sensors, Opal Wearable Sensors,	X	X	X	X	X	
LEAP Obstacle Course			X			
MATLAB						X
Manual Stop watches			X			
Mock M4 Weapon		X	X	X		
Paper data collection sheets and electronic questionnaires	X	X	X	X	X	
SHOTMAXX watch time				X		
SPSS Statistics V21,						X
CCO Unit	X			X		
USB response device,		X				
Windows Tablet with audio and USB (full size) ports		X				